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ANALYSIS OF DRIVER REACTION TO WARNING DEVICES AT A HIGH-ACCIDENT RURAL GRADE CROSSING

Eugene R. Russell

PURDUE UNIVERSITY
INDIANA STATE HIGHWAY COMMISSION

Final Report 74-16

ANALYSIS OF DRIVER REACTION TO WARNING DEVICES AT A HIGH-ACCIDENT RURAL GRADE CROSSING

TO: J. F. McLaughlin, Director
Joint Highway Research Project

August 28, 1974
Project: C-36-59N
File: 8-5-14

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

The attached report titled "Analysis of Driver Reaction to Warning Devices at a High-Accident Rural Grade Crossing" has been authored by Eugene R. Russell, Graduate Instructor in Research on our staff, under the direction of Professor H. L. Michael. The Report is the Final Report on the HPR Part II Research Study titled "A Field Evaluation of Driver Information Systems for Highway-Railway Grade Crossings".

This report includes the data collected during the after study of the grade crossing near Goldsmith, Indiana, of the N & W Railroad and US 31. The after study was with gates installed, larger flashing lights, and strobe lights on the gate arms. The analysis of before and after driver reactions to the warning systems are reported. The major finding of the study is that the gate system is a more effective warning system in alerting approaching drivers to the approach of a train than flashing lights without gates.

This Report is submitted as fulfillment of the objectives of the Study. It also will be forwarded for review, comment and similar acceptance to TSHC and FHWA.

Respectfully submitted,

Harold L. Michael

Harold L. Michael
Associate Director

HLM:jal

cc: W. L. Dolch
R. L. Eskew
G. D. Gibson
W. H. Goetz
M. J. Gutzwiller
G. K. Hallock
M. L. Hayes
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G. T. Satterly
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H. R. J. Walsh
E. J. Yoder
S. R. Yoder

Final Report

ANALYSIS OF DRIVER REACTION TO WARNING DEVICES AT A HIGH-ACCIDENT RURAL GRADE CROSSING

by

Eugene R. Russell
Graduate Instructor in Research

Joint Highway Research Project
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15. Supplementary Notes Conducted in cooperation with U.S. Department of Transportation Federal Highway Administration. Research Study titled "A Field Evaluation of Driver Information Systems for Highway-Railway Grade Crossings".

16. Abstract The objectives of this research were to analyze the effect on motorists of improving the warning devices at a high-accident, rural grade crossing, from 8-inch flashers to automatic gates and 12-inch flashers activated by a Marquardt speed predictor and having additional strobe lights; to evaluate suitable parameters to make the analysis; to study accident history and site conditions and relate these to motorist reaction to the system - before and after; and to evaluate the data collection system itself.

Spot speeds were taken at eight points on each approach to obtain an approach speed profile for various groups under various conditions after the signal system was improved. These were compared to similar data taken before system improvement.

It was shown that an activated gate arm can be as effective in slowing the average approaching vehicle as a train across the road. Train and signal conspicuity were a problem and contributed to the poor accident record of older drivers. The Strobe lights made the warning system more visible after activation.

Most drivers approach a grade crossing safely and mean speed of various groups shows trends but is a relatively weak parameter to test effectiveness, because they do not isolate the occasional, unsafe driver. Percent reduction of fastest cars, along with examining individual "fastest" cars, is a better parameter than mean speeds and decelerations to show improved effectiveness.

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ABSTRACT

Russell, Eugene Robert. Ph.D., Purdue University, August 1974. Analysis of Driver Reaction to Warning Devices at a High-Accident Rural Grade Crossing. Major Professor: Harold L. Michael.

The objectives of this research were to analyze the effect on motorists of improving the warning devices at the Goldsmith grade crossing, a high-accident, rural grade crossing, from 8-inch flashers to automatic gates and 12-inch flashers activated by a Marquardt speed predictor and having additional strobe lights; to evaluate suitable parameters to make the analysis; to study accident history and site conditions and relate these to motorist reaction to the system - before and after; and to evaluate the data collection system itself.

Spot speeds were taken at eight points on each approach to obtain an approach speed profile for various groups under various conditions after the signal system was improved. These were compared to similar data taken before system improvement. Similar raw data were available from FHWA and were analyzed to supplement results

It was shown that an activated gate arm can be as effective in slowing the average approaching vehicle as a train across the road. Visibility of gate arms before activation appeared to make the motorist more aware of the crossing even without signals activated. Train and signal conspicuity were a problem and contributed to the poor accident record of older drivers. The strobe lights made the warning system more visible after activation.

Most drivers approach a grade crossing safely and mean speed of various groups shows trends but is a relatively weak parameter to test effectiveness, because they do not isolate the occasional, unsafe driver. Deceleration rates were not high before or after but this fact is attributed to the need for long-term studies to "catch" the late-braking driver. Percent reduction of fastest cars, along with examining

individual "fastest" cars, showed reductions of all cars 75 mph and cars on the southbound approach 65 mph and is a better parameter than mean speeds and decelerations to show improved effectiveness.

CHAPTER 1: INTRODUCTION

Statement of the Problem

Highway-railway grade crossings constitute a hazard to both the highway traveler and railroad equipment and personnel and in recent years, there has been much written concerning the magnitude of the problem. It is not uncommon to find different accident figures quoted in different publications, and many times there is confusion regarding what they really mean.

One reason for the confusion in statistics on accidents at rail-highway grade crossings relates to the fact that there is need for better reporting and coordination of all transportation related accidents. Reporting has too often been superficial and fragmented among uncoordinated agencies.

A 1971 report to Congress summarizes the magnitude of the problem and categorized rail-highway accidents (1).[1] The more severe train-vehicle accidents at public grade crossings are reported to the Federal Railroad Administration. In accordance with their regulations, these only include those accidents which result either in: 1) a fatality, 2) injury to a person sufficient to incapacitate for a period of 24 hours in the aggregate during the 10 days immediately following or, 3) more than $750 damage to railroad equipment, track or roadbed. These "reportable" accidents at public grade crossings total about 4000 per year.

All train-involved grade crossing accidents as reported to state governments by police or drivers total about 12,000 per year. Roughly 1500 fatalities and 7000 injuries annually result from these accidents. Discrepancies and/or confusion in the literature result when authors

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[1] Numbers in parentheses refer to the Bibliography.

report the "4000" figure as the total of all train-vehicle accidents instead of the true "12000" as the total of all train-involved accidents which occur at the grade crossing.

In addition, there are an estimated 28,000 accidents which occur in the vicinity of, and are directly related to the presence of, a grade crossing but do not involve impact with or by a train (2). These are less severe but do result in an estimated 280 fatalities per year (1).

It has only been in recent years that a reasonably accurate inventory of the total number of grade crossings has been available. There are approximately 232,000 grade crossings in the United States, an average of one per mile of railroad, of which 155,000 are in rural areas and 77,000 are in urban areas (1). In addition, there are about 140,000 private road grade crossings (1).

Of the 232,000 public grade crossings, 22 percent, or 48,500, have some type of train-activated protective devices (2). Of the 12,000 vehicle-train collisions occurring at public grade crossings, over 40 percent of these accidents occur at crossings which have some form of active protection (2). Although other factors such as train and motor vehicle volumes are involved, it would appear that present active protective devices are less effective than is desirable.

Accident statistics show that since 1920, 86,000 persons have been killed, mostly in vehicle-train collisions (1). In the last decade alone, over 15,000 people have been killed (3). Even though accidents at rail-highway grade crossings amount to less than .1% of all highway accidents, they result in 2.7% of the total fatalities; and have a fatality/injury ratio of 1/2.7. This ratio, compared to 1/35 for general highway accidents, is an indication of the severity of grade crossing accidents, second only to airplane crashes.

The grade crossing problem is even more serious in Indiana. In the period 1965 to 1968, railroad grade crossings in Indiana accounted for 0.4 percent (0.1 for U. S.) of the total accidents and 6.0 percent (2.5 for U. S.) of the total fatalities (4). Indiana consistently has had a large number of railroad crossing accidents, primarily because of its large number of grade crossings.

It is especially important to look at rural grade crossing accidents as the higher operating speeds at such crossings are reflected in accident severity. During the period 1966 to 1968, rural Indiana railroad crossing accidents averaged 31 percent of the total grade crossing accidents; however, fatalities averaged 56 percent of the total fatalities (5). Thus it would seem that rural grade crossing accidents, at least in Indiana, are more severe than urban grade crossing accidents.

It should also be noted that although all grade crossings average only one traffic accident every 22 years, some grade crossings have a number of accidents every year. For example, one crossing on U. S. 52 in Indiana had at least one fatality and four total accidents each of the three years (1969 to 1971) (5). These accidents occur despite automatic protection in the form of flashing lights. It is evident that present protection systems, short of complete grade separation, are at best only partially successful.

In the past, whenever there has been an intensive effort to reduce the grade crossing accident rate, the effort was successful. Thus, there is reason to believe that a properly directed improvement program would achieve positive results. In the Report to Congress, it was estimated that at least 3000 improved protection installations should be made annually for the next 10 years at an expenditure of $75 million/year (three times the current rate) and that this expenditure of resources would eliminate nearly 4000 vehicle-train collisions and save 500 lives annually (2).

A Department of Transportation study showed that for a 48-year period from 1920 through 1967, whenever a new grade crossing protection improvement program was initiated, casualty reduction was noticeable. This study used the statistic "casualty ratio" as a measure of meaningful comparison, so that comparisons take into account increases in both vehicular and train traffic that have occurred over the years. As defined below:

$$\text{Casualty Ratio} = \frac{\text{Number of Casualties (Each Year)}}{\text{Exposure Factor (Corresponding Year)}}$$

Where,

$$\text{Exposure Factor} = \frac{\text{Train Miles} \times \text{Motor Vehicle Miles}}{10^{18}}$$

In terms of casualty ratio, the study drew two significant conclusions (1, 6, 7):

1. Grade separation and grade crossing protection programs have resulted in a marked decrease in highway-railroad grade crossing casualties. If the casualty ratio in 1967 had been the same as it was in 1920, the grade crossing casualties in accidents involving motor vehicles in 1967 would have been about 55,000 instead of 5,246, and:
2. Since 1958, the trend of grade crossing casualties has been upward and the casualty ratio has not been improved, thus indicating that more effort is now necessary to bring about a reduction in casualties in the face of a rapidly increasing motor vehicle traffic.

It is difficult to determine exactly in what direction the effort should be directed, particularly with limited funds available, but there are indications that new forms of driver information systems are needed at railroad grade crossings.

The federal aid highway act of 1973 set aside a total of $175 million dollars over a three-year period for grade crossing projects on the federal-aid system. At least half of this is specified for protective devices. Additional funding for projects off the federal-aid system was not specifically funded; however, grade crossing safety projects in this category may be a part of a state's safety improvement program. Many people feel that the amount is insufficient. Nevertheless, the amounts available should be spent wisely. In order to do this, more must be known about the problems at highway-railroad grade crossings. This means that more research needs to be conducted and that this research must be done as economically and effectively as possible.

Very little is known regarding the effectiveness of existing, as well as proposed, innovative grade crossing protective devices. Sonnefield, at a recent (1972) grade crossing safety symposium workshop, pointed out the inadequacy of police and railroad accident reports for obtaining meaningful statistics on accident causation and contributing factors (8):

> My only objective in indicating these things is the need to show more detailed information so that we can attempt to reconstruct accidents, if not on a wholesale basis at least on a selective basis, and attempt to get at the cause and establish some meaningful predictive procedures.

Thus, it is usually very difficult to determine the inadequacy of a particular protection system from individual accident reports.

The only true measure of the effectiveness of any grade crossing protection system is a long-term reduction in accidents. Accident reduction must be measured over a long period for a single crossing or aggregated over a great number of crossings for a given type of protection. At a single crossing the accident experience immediately following any protection change not only is not a good indication, but may be misleading. This is true because, unfortunately, most protective devices are placed at crossings because of some crises involving an unusual number of accidents for some given period. In the following period there probably will be a reduction even if nothing had been done. This is simply a basic law of statistics. It is possible, therefore, for some added protection to be given credit for accident reduction over a short period of time where no credit is due.

In addition to lack of knowledge on driver reactions to various grade crossings situations, and particularly their reactions to the whole range of present standard protective devices, there is evidence that new protective devices are needed in some instances. Many non-standard protection devices are being installed or proposed. However, relatively few of these innovations are field tested or evaluated for driver reaction and compliance. The problem of testing new devices is a very complex one. As expressed by Hopkins and Hazel (9)

> ...thus, beyond the question of reliability, any system which presents a significantly changed aspect to the motorist possesses a real challenge in the evaluation of its effectiveness, not only in devising and interpreting tests, but also in implementing them in actual service.

The focus in the past concerning railroad grade crossing problems has been primarily on hazard index formulas and accident prediction equations. The purpose of these formulas and equations has been to

determine priorities for the improvement of protection at specific grade crossings. Available protection, however, has not eliminated accidents at grade crossings.

The Need for Improved Systems

A relatively inexpensive warning system is needed at crossings with high volumes, high-speed traffic and/or high accident records. A system is needed that would approach the safety of a separation structure at a fraction of the cost. A system is needed that will have a strong, positive impact on the driver. Recent research emphasizes this last statement.

In a paper summarizing recent grade crossing research for the American Railway Engineering Association, Michael made the following observations (10):

1. Advance warning to the motorist at an approaching railroad crossing and (informing him of) his responsibility throughout are today generally inadequate.
2. There is a need for the development of low-cost protective devices of both the railroad-ahead warning type and train-approaching warning type.
3. Motorists need to be more impressed with the importance of the train-vehicle hazard.

In the same paper, Michael discussed the importance of improving driver information systems at grade crossings:

> It is also clear that information needed most by the motorist concerns itself with emphasis on his responsibilities at a crossing and in seeing an approaching train in time for him to stop. Anything that can be done to improve getting that information to him will improve safety at the crossing.

Mr. William B. Johnson, President of the Illinois Central Railroad, at a recent national conference on rail-highway grade crossing safety remarked (5):

> We need uniform, better signs in advance of and at crossings. It seems to me that present signs were designed for auto speeds much lower than the autos presently in use. Crossing signs sized and spaced for the Model "T" era preceding the modern automobile era are obviously obsolete and should be retired.

If every driver could be taught to have the proper respect for present highway-railroad grade crossing protection devices and could be conditioned to proceed cautiously, there would obviously be a great reduction in vehicle-train collisions at highway-railway grade crossings. In particular, if every driver was conditioned to react to present railroad advance warning signs, i.e., to become mentally alert and physically prepared to stop when necessary, grade crossing accidents could possibly be greatly reduced. Human nature, however, is such that the prospect of educating and conditioning all drivers to react in such a manner is pure idealism.

Studies and accident case histories show many drivers develop unsafe attitudes toward grade crossing protection devices of all types, even activated, automatic devices and particularly toward passive protection devices. When a motorist crosses the average railroad track at some random moment of a day, statistically there is a very small probability that it will be occupied by a train. He may use a crossing (or several crossings) for days, months, or even years without ever meeting a train at a grade crossing, and become so conditioned to the ever present railroad advance warning signs and no trains that the signs become meaningless.

A study of the obedience to stop signs, placed at grade crossings in Lincoln, Nebraska, sheds light on driver attitudes at grade crossings (11). The study found a willful disregard of stop signs placed at railroad grade crossings which was far higher compared to their disregard at street intersections. Even the stop sign, to which obedience is sacrosanct to most drivers, is ignored by some drivers when placed at a railroad grade crossing.

Conditions differ at individual crossings, but nationwide driver disregard for warning devices at highway-railway grade crossings is all too common. These situations at railroad grade crossings emphasize an outstanding example of human nature, i.e., when people are alerted unnecessarily they begin to disregard the warning. Yet drivers are expected, theoretically at least, to become immediately alert and responsive to every passive, railroad advance-warning sign. Accident records prove that it doesn't always work, even under ideal conditions.

At a recent grade crossing safety conference, Conner mentioned this aspect of the problem (12):

> The driver's attitude toward train conflicts varies considerably. As trains are very seldom encountered by him in his normal driving tasks he becomes unconcerned with the possibility that he may encounter a situation that is dangerous to him. Then when the dangerous situation is presented to him he is both awed, and frightened by it. In this condition he is not likely to act in a predictable or rational manner.

In regard to improvement of devices, the Voorhees Report (13) states that the greatest immediate opportunity for improvement for a motorist's decision-making process is in the area of improving passive protection at railroad grade crossings. There will always be a need for a family of passive devices tailored to meet a range of situations where active devices are not economically feasible.

The above study proposed different sets of advance warning sign sequences to better inform the motorist of his obligations at the crossing. For example, there are two main categories of obligations (13):

1. Where the motorist would have to watch for a signal which would indicate the approach of a train, i.e., automatic signal protection at the tracks.
2. Where the motorist must determine for himself if a train is approaching, i.e., passive protection such as crossbucks.

The point stressed herein is that the study found the present advance warning sign in need of improvement, even at minor crossings where automatic devices are not warranted.

Although passive advance warning signs, in their present form or with new innovations, will be needed at most grade crossings as the Voorhees report recommends, a different type of warning is needed at grade-crossings on high-speed heavily traveled routes. Advance warning with a much greater impact is needed. High accident records at many crossings, particularly on high-speed highways emphasize the fact that current automatic signals and passive advance warning signs are inadequate.

In regard to communications at railroad grade crossings, Conner (12) points out a need for the driver being told what he is expected to do and the problem of how to communicate this to him. Modern vehicles include radios, air conditioners, heaters, and excellent insulation which tend to isolate the driver from outside sounds and detract his attention from conditions at grade crossings. There may need to be more reliance on improved visual devices.

New and faster trains will add to the problem. Even with adequate sight distances the ability of drivers to estimate the closing speed of high speed trains and make a reliable "stop or go" decision may be poor. Williamson concluded that more estensive use of sophisticated electronic hardware to detect the speeds of trains and give uniform warning times, such as that being used by some railroads is needed (14). At present, these systems should be considered for use at all crossings.

In a recent report by Richards of the Texas Transportation Institute on rail-highway grade crossing safety improvement programs, one conclusion drawn from the analysis of rail-highway accidents occurring on the Texas highways is that (15): "The type of protection installed at rail-highway intersections may not be as effective in the reduction of accidents as often assumed."

Statistics from the above report showed that 10.4 percent of the total accidents were attributed to "braking late" and 48 percent to "ignored signal" (15). These statistics indicate that in over half (58.5 percent) of these accidents, the information system did not have the desired impact on the driver, because if it had, he would not have braked late, nor would he have ignored the signal.

There are situations where the present, standard, automatic signal protection at railroad grade crossings is apparently doing its job because not all crossings have bad accident records. On the other hand, there are too many situations where the present standard, automatic signal protection, is obviously not sufficient because these crossings do have bad accident records. There are probably crossings where the grades would be separated if money were readily available for this purpose, but since it is not, the latest technology and innovations in

driver information systems might be useful in providing the additional protection needed.

There is also another facet of the accident problem at railroad grade crossings that needs attention. Currently there are about 40,000 accidents in the vicinity of railroad grade crossings. About half of those not involving a train are rear-end collisions involving two or more vehicles (16). An effort should be made to incorporate into advance warning systems the capacity to alert drivers to conditions ahead which result in this type of accident. Such conditions include vehicles that must make a mandatory stop at railroad grade crossings and present a hazard of their own, independent of train movements.

The Voorhees Report (13) estimated that mandatory stops were responsible for 13.3% of the accidents at railroad grade crossings. The technology to warn of this type of hazard is currently available, and it should be developed to determine its potential for accident reduction.

The Need for More Research

There is need for more research to obtain performance data on innovations that would be effective alternatives. As stated by James Wilson (17), Chairman of the National Joint Committee on Uniform Traffic Control Devices 1967-1970,

> ...Compared to research in other highway related fields the amount for traffic control devices is minimal. It's about time industry and government meet the demands of these times to alleviate motor vehicle crashes and inefficient operations of our streets and roads...More information on new and innovative traffic control devices must be available to decision makers...

Wilson was not talking specifically about devices at grade crossings, but it certainly applies. Contrary to what many may believe because of the great volume of recent reports on grade crossing safety, the problem is not well understood and has not yet been well researched. This situation is discussed by Eicher who noted that although there were many notable studies on grade crossing safety the problems were not well understood (18):

> The symptoms of the problem or the number of collisions involving certain types of vehicles at certain types of grade crossings are reasonably well documented, but the problem itself is not.

In an attempt to formulate and validate a simulation flow model, Eicher found while searching the literature that very little is known concerning how the important characteristics of grade crossings interact. He therefore had to resort to judgment in developing sometimes questionable and/or vague relationships between the variables, because answers are needed to the following questions (18):

1. How do drivers respond to an approaching train when it is within the line of sight of the driver, and how does this response vary as a function of the motor vehicle's speed, the train's speed and the position of the motor vehicle and train?
2. How do drivers respond to passive as well as active warning devices and what factors influence their compliance to a directive to stop because of an approaching train?

Research of this type is in itself expensive, as are railroad grade crossing improvements; however, consider the following point of view. Robinson (19) expressed the feeling that the question (spoken or unspoken), "How much is society willing to pay for added crossing safety and, how the funds are going to be collected?" should not permeate rail-highway safety conferences and symposiums as it does. Not because it is not important, but because it is not properly a question for engineers and administrators to answer. As expressed by Robinson (19):

> The public's decision will be made by the public's representatives in board rooms and legislative halls. Our job as administrators and as professionals is to assemble the facts and call these to the attention of the policy groups as the basis for a sound decision.

The Voorhees report is the most comprehensive and perhaps significant of all research studies in highway-railway grade crossing safety that has been done to date. Even though this report is a great contribution to current knowledge of grade crossing safety, it did not attempt to answer the questions presented above.

Insight into the direction that future efforts must take was well presented by Koltnow; he praised many steps taken by Congress but cautioned (46):

> None of these steps, however, is likely to make a substantial change in the crossing accident experience in the next few years, unless other important steps are also taken.
>
> One of these steps is to insure that railroad crossing accidents are considered accurately in relation to other safety needs in each state and local agency.
>
> A second is to encourage public agencies to know which crossings are most in need of improvement and most susceptible to various treatments.
>
> The third is to develop a better understanding of <u>all</u> the factors that lead to crossing accidents, and a more complete and effective package of countermeasures.

These noble objectives cannot be met without a continuing program of research. The level and type of research program necessary, particularly field testing the effectiveness of both current and proposed devices to arrive at -- "a more complete and effective package of countermeasures," cannot be accomplished effectively without resolving some of the issues which affect good interagency cooperation.

CHAPTER 2: REVIEW OF LITERATURE

General

Much of the literature relating to grade crossings is widely scattered in little-read or limited-distribution publications such as State Police accident reports, Interstate Commerce Commission Reports, bulletins of various railroad associations, studies by area planning commissions, State and local government highway departments and similar other relatively obscure sources. Many of these published reports relate to a specific problem of a specific group. There has been little actual research, particularly "field research" or an attempt to obtain basic data.

The literature reviewed herein will be that which has been the most significant in recent years. This includes material from some significant reports of government agencies and transportation institutes, proceedings of conferences formed to discuss the grade crossing problem, and recent research.

Predictive Equations

This section presents the state-of-the-art of accident prediction at a railroad-highway grade crossing. There are merits in the various approaches reviewed. The obvious complex nature of the "accident problem," where the driver-vehicle-roadway system interacts with the protection system, environment and train, leads to short-comings in predictive models. The problem of finding or developing reliable parameters that relate directly to accident experience is a formidable one

Schoppert and Hoyt (1968) point out that (13):

> The bulk of previous research falls into three general areas, as follows:
>
> 1. Development of hazard indexes
> 2. Development of predictive equations
> 3. Analysis of before-and-after accident data and other miscellaneous studies.

In a later report (1969) Schoppert emphasized that early research was directed along these lines because of lack of reliable data. He reviews the argument of critics of the method that (21):

> ...these indexes are not appropriate for allocating funds among competing crossings primarily because the ranking they lead to is not based on economic considerations, and the resulting ordering is not cardinal.

Schoppert reviews the "state-of-the-art" of hazard index locations (21). Most hazard indexes are of the form:

$$I.H. = \Sigma_i \; a_i X_i \qquad 1$$

where: the set of X_i's consists of motor vehicle and train volumes and speeds and the characteristics of the site. The a_i's are weighting factors. The weights (a_i's) are subjectively assigned with frequently no statistical justification.

The normal procedure in these approaches is to collect data on whatever characteristics the researcher believes to be significant and to relate this to accident history by regression or factor analysis techniques. Some of the resulting equations are relatively simple, others complex. Some consider a few factors, others a more complete list. Schultz (22) appears to have included the most complete list and it is presented here as an example of the types of factors considered in this type of research. The variables in Table 1 were considered by Schultz (22).

As expected, Schultz developed rather complex equations. In subsequent papers, Schultz and Oppenlander (23) and Berg, Schultz and Oppenlander (24) identified the following as important predictive variables:

TABLE 1. VARIABLES CONSIDERED BY SCHULTZ FOR GRADE CROSSING HAZARD EVALUATION (Source: Ref. 22)

1. Vehicle type
2. Vehicle age
3. Out-of-Country
4. Out-of-State
5. Number of Occupants
6. Actual car speed
7. Actual train speed
8. Vehicle defects
9. PCC surface
10. Asphalt surface
11. Gravel surface
12. Dry pavement
13. Ice or snow
14. Clear weather
15. Darkness
16. Windows
17. Alcohol
18. Male driver
19. Driver age
20. Personal injury
21. Fatality
22. Monday
23. Tuesday
24. Wednesday
25. Thursday
26. Friday
27. Saturday
28. Sunday
29. Painted crossbucks
30. Reflectorized crossbucks
31. Flashers
32. Gates
33. No protection
34. Stop sign
35. White edge line
36. Highway gradient
37. Railway gradient
38. Highway curvature
39. Railway curvature
40. Number of tracks
41. Pavement width
42. Advance warning sign
43. Pavement crossing markings
44. Number of businesses
45. Number of advertising signs
46. Minor obstructions
47. Number of houses
48. Angle of view
49. Intersection angle
50. Average freight train speed
51. Number of passenger trains
52. Number of freight trains
53. Average train speed
54. Trains per day
55. ADT
56. Average car speed
57. Sum of 44, 45, and 47

1. No. of track pairs
2. Highway pavement width
3. Train volume
4. Average daily traffic volume
5. Sum of distractions (no. houses, businesses and advertising signs)

As complex as their equation was (I.H. = $-0.185 + 0.079X_{40} + 0.021X_{41} + 0.011X_{54} + 0.013X_{55} + 0.024X_{57}$) it only explained 18 percent of the accident occurrence leading to the conclusion that, "railroad-highway grade crossing accidents are predominantly the result of driver characteristics and/or chance" (23).

It is this latter conclusion that is, possibly, more significant than the prediction equation itself. Other conclusions of the study that relate to studies herein are (23, 24):

> Accident victims are predominantly young male drivers, traveling alone. Seventeen percent of all vehicles have evidence of mechanical defects. Windows were closed on most vehicles minimizing the importance of audio warnings. Most accidents occur during the favorable driving conditions of clear weather, daylight hours and dry pavements.

There was no positive evidence, however, to indicate that the fact that some of the involved vehicle had mechanical defects was a contributing factor to the accidents.

Berg, et al., made another important observation (25) relative to driver observance of railroad-highway grade crossing protective devices. In a compliance study comprising 153 observed motorists, it was found that there was 46 percent compliance at flasher installations and 90 percent compliance at automatic gates. For a comprehensive review of research in this area the reader is referred to Schoppert (13), Appendix A, and the 75 references contained therein.

In Chapter 1 of Traffic Control and Roadway Elements - Their Relationship to Highway Safety, Richards (26) summarizes the "selected hazard index formulas." These are presented below in Table 2, primarily to emphasize the variety of output that one obtains from this type of research effort.

The set of relative hazard factors for selected protective devices that is probably most commonly used is from the Voorhees Report (13) and is presented in Table 3.

TABLE 2. SELECTED HAZARD INDEX FORMULAS (Ref. 26)

Peabody and Dimmick Formula (63)*: $A_5 = 1.28 \dfrac{V^{0.170} + T^{0.151}}{P_c^{0.171}} + K$

Mississippi Formula (25): $H.I. = \dfrac{\frac{SDR}{8} + A_5}{2}$

New Hampshire Formula (54): $H.I. = VTP_f$

The Ohio Method (59): $H.I. = A_f + B_f + G_f + L_f + N_f + SDR$

Wisconsin Method (87): $H.I. = \dfrac{T\left(\frac{V}{20} + \frac{P^1}{50}\right)}{5} + SDR + A_e$

Contra Costa County Method (23): $H.I. = TZ\left(1 - 2.718^{\frac{-Vt}{1400Z}}\right)$

The Oregon Method (62): $H.I. = \left(V_1T_1P_f + 1.4V_2T_2P_f\right)\dfrac{A_e}{A_5}$

North Dakota Rating System (58): $H.I. = (N_f + L_f) + (P_f + D_f + G_f + X_f) + (VT_f) + SDR$

Idaho Formula (33): $H.I. = V_f \times T_f(CB_f + SDR + N_f + Y_f)$

Utah Formula (89): $H.I. = \dfrac{T}{1000}\left[\left(\frac{P}{10} + \frac{F}{20} + \frac{S}{30}\right) + SDR + N_f + X_f + R_f\right] + 2A_e + \dfrac{P^1}{100{,}000}\left(\frac{P}{10} + \frac{F}{20} + \frac{S}{30}\right) - P_f$

City of Detroit Formula (50): $H.I. = \dfrac{T}{1000}\left[\left(\frac{P}{10} + \frac{F}{20} + \frac{S}{30}\right) SDR + N_f + X_f + R_f\right](100\% - \%P_f) + 2A_e$

TABLE 2. (CONTINUED)

SYMBOLS:

A_5 = Expected number of accidents in 5 years
A_e = Accident experience
A_f = Accident probability factor
B_f = Train speed factor
CB_f = Type and speed of train factor
D_f = Alignment of track and highway factor
F = Number of freight trains in 24 hours
G_f = Approach gradient factor
H.I. = Hazard index
K = Additional parameter
L_f = Angle of crossing factor
N_f = Number of tracks factor
P = Number of passenger trains in 24 hours
P^1 = Number of pedestrians in 24 hours
P_e = Protection coefficient
P_f = Protection factor
S = Number of switch trains in 24 hours
SDR = sight distance rating
t = Time crossing is blocked
T = Average 24-hour train volume
T_1 = Average daylight train volume
T_2 = Average train volume during dark hours
T_f = Train volume factor
V = Average 24-hour traffic volume
V_1 = Average daylight traffic volume
V_2 = Average traffic volume during dark hours
V_f = Traffic volume factor
VT_f = Exposure factor
X_f = Condition of crossing factor
Y_f = Severity factor
Z = Number of traffic lanes

* The reference numbers in parentheses in the table above refer to the references at the end of Chapter 1 by Richards (26) and are not repeated herein because the publication is readily available.

TABLE 3. RELATIVE HAZARD RELATIONSHIPS FOR PROTECTIVE DEVICES AT RAILROAD GRADE CROSSINGS (Ref. 26)

Type of Protection	Relative Hazard
Crossbucks	1.00
Stop Signs	0.58
Wigwags	0.34
Flashing Lights	0.20
Gates	0.11

Another noteworthy study in this area was done by Bezkorovainy and Holsinger (27). They conducted a study to determine which of eleven established accident prediction formulas should be used to rate railroad crossings in the city of Lincoln, Nebraska. All eleven formulas were used independently to rate all of Lincoln's 180 grade crossings. Bezkorovainy and Holsinger concluded that all eleven formulas were "all equally good or all equally bad."

A second part of the study concluded that the New Hampshire formula was optimum for local conditions. It is (27):

$$H.I. = VTP$$

where H.I. = hazard index

V = average 24-hour traffic volume

T = average 24-hour train volume

P = protection factor, gates = 0.1, flashing lights = 0.6, signs only = 1.0

The Hazard Index research, however, was not getting to the basic causes of accidents. Considering 57 initial variables, Schultz's resultant equation only explained 18 percent of the accident occurrence. Thus it is apparent that driver characteristics must be considered. Schoppert makes an excellent point in this regard (13):

> Accidents depend on such factors as driver skill and perception, etc., which would be impossible to quantify in any consistent way. It is obvious also that many accidents occur from essentially random causes and so any predictive equation is bound to "explain" less than 100 percent of accident behavior, even in the very long run. However, even an equation which made use of only the criteria which had major effects would be quite useful.

Theoretical Basis of Quantitative Evaluations

Schoppert extended the hazard index approach and developed statistical models (13, 21). These models appear to be the most sophisticated of those that appear in the literature. He relies on the Poisson distribution, since accidents either happen or they do not happen in a given time period. One has to hypothesize that the distribution of accident frequencies is completely random with an average equal to the observed average.

Schoppert, et al., (13) compared expected and observed distributions of accidents by protection type and made two points, 1) the assumption of randomness was not necessarily the basic point violated and, 2) predicting the tendency toward accidents was desirable even though the randomness assumption does not hold. They developed the following model (13):

$$P = R(K + p) \qquad 1$$

where:

P = the probability of an accident

K = the probability of a vehicle arriving at a grade crossing occupied by a train

p = the probability of a train arriving at the grade crossing occupied by a vehicle

R = the risk that a driver will be unaware of his surroundings, hence will not, or cannot, take evasive action to avoid a pending collision, i.e., $R = 1$ implies unswerving drivers who are completely oblivious to all obstacles in their path; and $R = 0$ implies perfect information and complete awareness, hence no risk.

Using the above approach, the following equations were developed (13):

Summary of Equations

Crossbucks:

Highway volume below 500 per day:

$$x_1 = x_{10}(38.90)$$

Highway volume greater than 500 per day:

Urban

$$x_1 = x_{10}(30.57)$$

Rural

$$x_1 = x_{10}(30.35)$$

STOP Signs:

Highway volume below 500 per day:

$$x_1 = x_{10}(45.13 + 2.51x_7 + 13.5x_6)$$

Highway volume greater than 500 per day:

$$x_1 = x_{10}(11.44)$$

Flashing Light Signals:

Urban

$$x_1 = x_{10}(3.23)$$

Rural

$$x_1 = x_{10}(9.30)$$

Gates:

Urban

$$x_1 = x_{10}(3.23)$$

Rural

$$x_1 = x_{10}(1.93)$$

in which:

x_1 = accidents per year, scaled by 100;

x_2 = ADT;

x_5 = angle of crossing, acute angle; measured in degrees;

x_6 = total number of highway lanes;

x_7 = maximum absoluted approach gradient within 100 feet of crossing; and

x_{10} = probability of coincidental vehicle and train arrival or

$$\frac{x_3}{86{,}400}\left(1 - e^{-x_2/86400}\right)$$

in which:

x_3 = trains per day; and

x_2 = highway vehicles per day.

In summary, the above equations appear to be the most sophisticated, theoretical approach that can be found in the recent literature; however, many assumptions and simplifications were necessary in their development. They can be useful for ranking grade crossings.

One criticism, found in the literature, of using hazard index equations for relative rankings and/or priority ratings is that it does not include economic considerations. Determining appropriate accident costs is difficult. Putting an appropriate cost on a life is very difficult. For these reasons, accident costs are often ignored in highway economic studies, or when used, there is no general agreement as to their validity. However, it is becoming increasingly clear that any (and all) highway improvements should be cost-effective. Richards and Lamkins made attempts to improve these models by including incremental benefits in development of a priority index (15). Many assumptions have to be made regarding accident and fatality rates and costs as well as the effectiveness of an increment of protection. However, economic considerations cannot be ignored.

Equations from Accident Base

Huntington, Coleman, Eicher and Hunter conducted the most recent study to analyze accident potential for individual crossings using regression analysis, and for broad groups of crossings using summary accident statistics (28). The study confirmed previous efforts in that regression equations developed for individual crossings did not explain a significant amount of variation in accidents. It was decided to analyze accident potential for groups, using least squares regression on group means.

The study was conducted using a data base of over 16,000 crossings of which five years of accident data were available. The data were grouped into rural and urban locations and by six types of protection, 1) none, 2) stop signs, 3) crossbucks, 4) automatic gates, 5) flashing light signals and 6) "other active."

Multiple linear regression was used to relate the mean group train and highway traffic volumes. Even with the large data base, limitations in the number of points for the attempted regression led to the aggregation of protection type into active and passive.

The regression equation developed was (28):

$$\mathrm{Log}_{10}\ \overline{A} = C_0 + C_1 \log_{10} \overline{V} + C_2\sqrt{\overline{T}}$$

where:

$\overline{A}$ = mean number of accidents per crossing for five years in a group of crossings which carry highway and train traffic volumes within preselected ranges

C_i = coefficients of the regression

$\overline{V}$ = mean daily highway traffic volume in the group of crossings

$\overline{T}$ = mean daily train traffic volume in the group of crossings

The coefficients for the various group equations are given in Table 4 (28). As stated in the report (28):

> The primary use of the equations is to assess the savings in train involved accidents as a result of upgrading the crossing protection.

Figure 1 illustrates the four equations showing the expected 5-year accidents per crossing at various highway volumes for a fixed 10 trains per day. Figure 2 illustrates the expected 5-year accidents per crossing at various daily train volumes for a fixed highway volume of 2,500 vehicles per day.

Grade Crossing Safety Factors

There have been several significant, recent reports (1968 to 1972) that have made substantial contributions to the state of knowledge regarding grade crossing safety (1, 2, 9, 13, 15, 21). This group of reports has dealt primarily with review and analysis of accident data

TABLE 4. BEST-FIT EQUATIONS FOR GROUP-MEAN OBSERVATIONS TO PREDICT EXPECTED 5-YEAR ACCIDENTS PER CROSSING (Ref. 28, p. 36)

$$\mathrm{Log}_{10}\,\overline{A} = C_0 + C_1\,\mathrm{Log}_{10}\,\overline{V} + C_2\sqrt{\overline{T}}$$

Area-Protection Regression Coefficients

	C_0	C_1	C_2	R	N	E
Urban-Passive	1.813	0.321	0.164	0.90	20	0.022
Urban-Active	1.915	0.321	0.185	0.89	16	0.034
Rural-Passive	3.031	0.699	0.218	0.94	16	0.021
Rural-Active	2.624	0.487	0.209	0.87	13	0.040

R = multiple correlation coefficient
N = number of groups
E = standard error of estimate
$\overline{A}$ = mean number of accidents per crossing for 5 years
$\overline{V}$ = mean daily highway traffic volume in the group of crossings
$\overline{T}$ = mean daily train traffic in the group of crossings

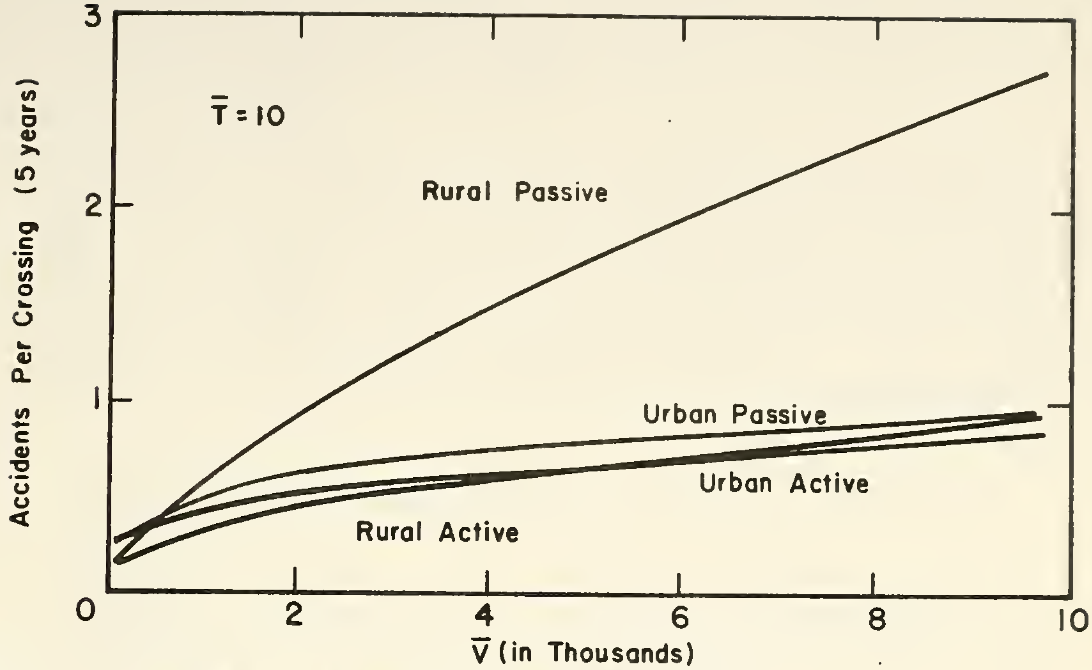

FIGURE 1: Expected Five Year Accidents Per Crossing for T= 10 (tpd)
(Source: Ref. 28)

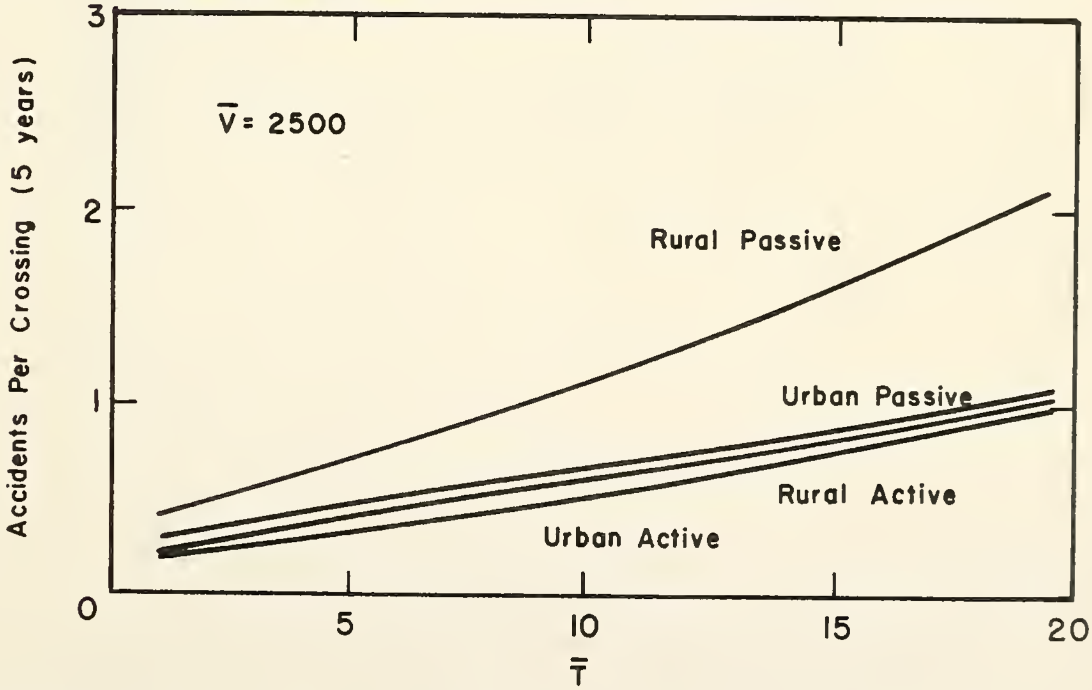

FIGURE 2: Expected Five Year Accidents Per Crossing for V= 2500 (vpd)
(Source: Ref. 28)

obtained from a wide variety of sources. For example, the Voorhees Report (13) obtained data from private sources, state highway departments, and regulatory agencies, including 15,000 accident reports from the Interstate Commission.

No attempt will be made herein for a complete review of any of these readily-available reports. None of these reports deals primarily with collection and analysis of field data. No attempt was made in any of them to determine basic data of driver reactions to grade crossings.

Schoppert and Hoyt developed formulae for probable accident rates for grade crossings. Conclusions of their study are paraphrased below (13):

> Flashing lights and gates reduce materially the numbers of accidents that occur at railroad crossings.
>
> On a per crossing basis, the incidence of accidents is very small, on the order of less than one every 10 years, therefore, a protection program should not be based on an individual crossings accident experience.
>
> Suggested, implicit cost assumptions for economic analysis are: cost per accident, $8,000; cost of flashing lights, $13,000; cost of gates, $26,000; cost to upgrade flashing light to gates, $13,000; cost of grade separation, $100,000; and economic life of improvement, 10 years (1968 costs).
>
> Equations were developed for nontrain-involved accidents:
>
> With automatic gates;
>
> $$EA = \frac{V}{100}(0.00866 + 0.00036\ T)$$
>
> All other protection types;
>
> $$EA = \frac{V}{100}(0.00499 + 0.00036\ T)$$
>
> where:
> EA = number of expected accidents
> V = number of vehicles per day
> T = number of trains per day
>
> (It should be noted that the "EA" with automatic gates is higher than for all other types of protection.)
>
> Vehicles that are required to stop at all railroad crossings account for approximately 13.3 percent of all accidents which occur when a train is present.

> Analysis of the accident data indicated that the major safety problem is caused by trains that appear to the motorist after the driver has passed his final opportunity to stop.
>
> For a large number of crossings, improved passive protection is needed to make the motorists' responsibility clear.
>
> The majority of grade-crossing accidents occur during the daylight hours; however, accidents "normalized" for highway volumes occur more frequently at night.

Richards and Lamkin (15) made a comprehensive study of grade crossing safety in Texas and reported on the statistical and economic aspects of the problem. From the analysis of rail-highway accidents occurring on Texas highways during the period 1962-1966, the following conclusions drawn (15):

1. Tractor-trailer trucks experience a relatively higher proportion of the rail-highway accidents than all other classes of motor vehicles.
2. When compared with all other classes of vehicles, tractor-trailer trucks experience a relatively higher proportion of rail-highway accidents in urban areas.
3. Most rail-highway accidents occur during daylight hours.
4. Approximately thirty percent of the rail-highway accidents occurring on Texas highways were at the intersection of farm-to-market roads and railways within urban areas.
5. The farm-product truck may have a higher frequency of rail-highway accidents than trucks used in other services.
6. The type of protection installed at rail-highway intersections may not be as effective in the reduction of accidents as often assumed.
7. Drivers over fifty years of age are less aware of hazards at rail-highway intersections than they are of all other types of motor vehicle operation hazards.
8. The condition of the motor vehicle does not appear to be an important factor in the cause of train-vehicle accidents.

9. It does not appear that the use of intoxicants is as significant in rail-highway accidents as generally reported for all motor vehicle accidents.

10. Although failure of the motor vehicle to stop at rail-highway protective devices displaying flashing red light appears to contribute to these accidents, excessive speed on the approach to the crossings is not reported as a significant contributor to rail-highway accidents.

The above list is typical, both in type and content, of the type of conclusions that can be drawn from analysis of accident data. Conclusions such as these can pinpoint contributions to the accident history of aggregated crossings, but not to basic causes, nor to specific crossings. This is essentially the same drawback that predictive equations have.

The report further points out another problem with using accident data. Each year about 800 rail-highway accidents occur in the state of Texas, however, in accord with FRA reporting requirements as previously discussed, only one-half of these accidents are reported to the Railroad Commission in Texas (15).

In response to the Railroad Safety Act of 1970, the Federal Railroad Administration and Federal Highway Administration, jointly, submitted to Contress a report identifying the extent and nature of the safety problem associated with railroad-highway intersections (1, 2). Some relative points brought out in this study are paraphrased below (1):

> The results of an economic analysis to provide an economic-order-of-magnitude of the problem indicate that if 15,000 crossings were provided with improved protection, accident costs would be reduced nearly three times the installation and maintenance cost of the improvement.
>
> Initial cost of installation of protective devices ranges from approximately $15,000 for installation of flashing lights to approximately $25,000 for installation of automatic gates. Train speed measurement devices add to the cost. Annual maintenance costs range from $750 to $1,250. Grade separations have an average cost range of $320,000 to $930,000 (1970 costs).
>
> All grade crossing accidents are to some degree "driver error." Any effective program for safety improvement should be driver oriented and consider his needs in approaching, traversing and leaving the crossing site as safely and efficiently as possible. That is, when a driver approaches a crossing he needs

to know if there is a train, 1) on the crossing, 2) approaching the crossing, or 3) not in the vicinity of the crossing. Automatic devices which give the driver a uniform advance warning time prior to arrival of the train significantly simplify the driver's task and substantially reduce motor vehicle-train collisions.

Currently available active crossing devices are flashers and gates. These are fail safe devices that are essentially effective in reducing accidents, but their cost has restricted their use to crossings with high train and motor vehicle volumes. Also, there is a need for more reasonably priced devices to measure train speed. This would permit their wider use and, 1) give added credibility to the signal's warning, and 2) reduce delay and operating costs.

Modifications to the train are being evaluated as likely aids to the driver in detecting the approach of a train. These include visibility and audibility modifications to the locomotive such as high intensity zenon lights and more effective use of paint.

Finally, in the conclusion to the executive summary, it is stated that (1):

> ... with the tremendous growth in motor vehicle miles, serious congestion on urban streets, and increasing interest in high-speed rail service as an alternative mode in transportation planning, improved highway and railway mobility has assumed new importance. Effective resolution of the grade crossing problem should consider both increased safety and more efficient use of the highway and railroad systems.

In the Report to Congress, Part II, alternative levels of improvement needs on a nationwide basis are determined and set forth. This analysis includes the number and type of improvements, costs, anticipated reductions in accidents and casualties, and total benefits (2). In regard to improvement needs the study made the following points:

> The economic analysis of protection was limited to flashing lights, automatic gates and grade separation structures. The results showed that grade crossing protection will return both greater overall benefits for a given level of investment than will grade separations.

Innovative Devices

Butcher conducted a recent (1973) extensive search of the literature for all available information regarding use of any type of

innovative grade crossing device (29). These include several innovative advance warning devices which have been installed in actual service, somewhere, and are either activated through rail circuitry or are in continuous operation.

The list of innovative devices that were uncovered and of possible merit are listed below in self explanatory categories.

Implemented Active Advance Warning Devices

1. Three horizontal yellow flashers (Los Angeles, California).
2. Neon "R X R GATE" Sign (Tracy, California).
3. Flashers on Stop Signs.
4. Neon "RR SIGNALS AHEAD" Sign (New Jersey)
5. Cantilever Red and Yellow Flashers (Indiana).
6. Yellow Flashers on Standard Advance Warning.
7. Texas System of Advance Warning.

Proposed Active Advance Warning Devices

1. Illuminated "STOP AHEAD" Sign
2. In-Vehicle Real Time Warning.
3. Variable Message Signs.

Implemented Active Devices at the Crossing

1. Ohio Special Lights and Signs.
2. Standard Traffic Signals in Lieu of Flashers (Michigan, others).
3. "WAIT - 2 TRAINS" Sign (Illinois).
4. Missouri Blinking Light.
5. Rotating Red Light with Highway Signal (California).
6. Indiana Green Light Signal (Monon Green).

Proposed Active Devices at the Crossing

1. Arizona Cantilever Crossbuck and Flasher Sign.
2. Various Light-Related Information Sources for the Crossing.

Some of the above innovations in the "implemented" category reported positive results, others did not. In most cases, however, no tests had been conducted to test their effectiveness. Some of the ideas in the "proposed" category could have merit, but they need to be implemented and tested. The relatively few innovations that have been implemented nationwide, with or without an adequate research program

to measure their effectiveness, appears to be a result of general reluctance to allow installation and testing of new methods.

The reader is referred to Butcher's study for a complete review of these innovative devices. It is of greater significance herein to note that there are not only few of these devices available; but that it is difficult to field test such devices. Questions of liability and cost apportionment are difficult to resolve. The Indiana Green Light Signal will be reviewed at greater length because information on this device is not generally available.

In the case of the Indiana Green Light Signal, or "Monon Green," Butcher made field observations at several locations where this signal is in use. This signal is only employed at locations where regular active protection would not be justified, such as low volume rural roads, especially those with poor sight distance and some private crossings. None are installed on Federal Aid Secondary or high volume roads. These devices are installed by only one railroad, Monon (now part of the Louisville and Nashville RR), and usually as the result of local pressure.

This installation is described as follows (29):

> The regular crossbuck is supplemented with a highway traffic "STOP" sign installed on each side of the crossing with an additional sign reading "When Light is Out." Adjacent to the "STOP" sign is an 8-foot mast with back-to-back traffic light units with green lenses. The green light is tied to the Railroads' APB block system circuits. The traffic light heads utilize 67-watt 120-volt bulbs displaying a green light to motorists approaching the crossing, provided no train has preempted the XR relay. On the approach of a train, the relay is de-energized and the green light is extinguished.

These "Monon Green Signals" (as they are commonly called) appear to be effective. Requests by local public bodies that the railroad install several more, indicate local public acceptance and confidence in the signal. The state has never considered use of the signal, and does not anticipate doing so because they are not authorized by the MUTCD. Also, their effectiveness has never really been proven and there is a possibility that they could confuse someone not familiar with them.

Hopkins and Hazel eloquently pinpoint the problem of field testing an innovative device (9):

> If the new system in some way conflicts with the operation of the original, very severe problems will result; no railroad is likely to risk an accident with an admittedly experimental protective system, and no other body (such as government) can be expected to accept full liability, particularly in this difficult area. (A common aspect of lawsuits is the alleged failure of the signals.) This difficulty is met directly when new signal devices, rather than activation techniques, are considered. In this second case, one must consider not only the technical operation, but how motorists will respond to a different means of indicating the imminent passage of a train. The victim of an accident under these circumstances may have a legitimate complaint that he did not understand the meaning of the warning. One can imagine the legal complexities which would result. Thus, beyond the question of reliability, any system which presents a significantly changed aspect to the motorist poses a real challenge in the evaluation of its effectiveness, not only in devising and interpreting tests, but also in implementing them in actual service.

The funding of grade crossing protection systems is a problem, particularly those off the federal aid system. Of the estimated 223,000 grade crossings in the U. S., 174,000 are off the aid system (1, 2). Many of these crossings are low-volume, low-hazard potential crossings; however, together they do account for 60 percent of the vehicle-train accidents (1, 2). Also, they account for 45 percent of the crossings that the FHWA Report to Congress recommends be improved.

The superiority of automatic, active signal devices at grade crossings is generally accepted. Funding and allocation of costs are serious drawbacks to the more widespread use of train-activated protective devices at approximately 175,000 grade crossings that do not have such protection.

Hopkins and Hazel (9) looked at the high-cost aspect of active protective devices as well as train-speed predictor systems. Their research dealt with the actual hardware in an attempt to design low cost components. They also studied the many problems associated with general acceptance and application of such new devices.

Hopkins and Hazel also consider cost-effectiveness, focused on the "more explicitly technological aspects" of the problem. They also give a perspective on the technology and the testing of new devices that is worth repeating (9):

> Technology will offer no easy answers, and, indeed, may make the task still more difficult. The variety of grade crossings, the complexities of human behavior, the weakness of existing data, and the basic rarity of crossing accidents (approximately 70 years between deaths at an average crossing) reduce any test and demonstration program, even if fairly elaborate, to little more than a good indicator, rather than definitive proof of effectiveness. It will be necessary, from time to time, to make decisions with quite inadequate information, based as much on intuition, experience, and wisdom as on engineering data.

Hopkins and Hazel (9) have an interesting approach to determine "warranted protection expenditures" for various classes of passive crossings. It is unique in that it establishes a range of warranted expense guidelines for expenditures within the bounds of cost-effectiveness criteria. The approach is summarized in the following paragraphs.

Using annual accident prediction equations for passive crossings developed by Schoppert (13), estimates of the number of these crossings in each of 36 different classes of rail and highway traffic, and taking the average cost of an accident as $20,000, data were developed covering all passively protected crossings, including the following data:

a. Number of crossings in category

b. Number of years between accidents

c. Annual fatalities (total) for category (there is approximately one fatality for every five accidents, so calculation of years between fatalities of annual accident rate is a trivial operation)

d. Annual accident cost per crossing.

Initial investment was charged at 5% of initial cost per year and maintenance also 5% of initial cost per year. For a favorable benefit cost ratio:

$$\text{Annual Accident Cost} > \text{Maintenance} + \text{Amortization}$$
$$\text{or} > 10\% \text{ of initial cost}$$

Thus; $$\text{Initial Cost} < 10 \times \text{Annual Cost}$$

The report's contention is that the cost of a protective system must be less than 10 times the predicted cost of accidents if protection is to be warranted on a cost-benefit criteria. Combining this concept with the data and grouping into expense classes, result in the breakdown in Table 5.

It is assumed that the degree of protection afforded in each case will reduce the cost of future accidents to zero, i.e., be 100% effective. Also, three types of data are not included: 1) motorist delay, 2) non-train accidents, 3) railroad expense other than maintenance.

The authors "admit" that the analysis is "sufficiently crude" that a correction for motorist delay would be meaningless. They further point out limitations to a strict application of cost-benefit criterion (19): 1) the task of taking and maintaining a fully adequate grade crossing inventory and keeping all parameters current, is such an extremely difficult task that any single piece of data must be viewed with skepticism, 2) accident data are similar (in respect to #1) and the past history of accident data has been one of very cursory investigation, 3) even assuming adequate data there are both costs and benefits either inadvertently, or through impossibility to measure, that are ignored.

In presenting the limitations of their approach, Hopkins and Hazel appear to have no less a valid approach than can be found in the literature. They are, perhaps, more "honest" in the presentation of the various shortcomings of their study. It is believed that one conclusion merits emphasis (9):

> ... It is found that a very large number of crossings warrant only very limited expense and account for a very small percentage of deaths.

This report also deals with the actual hardware of innovative devices, such as, "micro-wave telemetry alternative to conventional track circuits and possible crossing-located radar and impedance train detection systems." It is appropriate to review the types of

TABLE 5. CATEGORIZATION OF GRADE CROSSINGS WITH PASSIVE PROTECTION, IN TERMS OF WARRANTED PROTECTION EXPENSE (Source: Ref. 9, p. 13)

Class	Warranted Expense	Estimated Number of Crossings	Predicted Total Deaths	Approximate Total Cost of Accidents
1	Under $300	65,100	7	$ 0.7 Million
2	$300 - $1000	48,350	29	$ 2.9 Million
3	$1000 - $3000	32,540	55	$ 5.5 Million
4	$3000 - $10,000	15,510	84	$ 8.4 Million
5	$10,000 - $30,000	13,950	222	$22.2 Million
6	$30,000 - $100,000	3,480	215	$21.5 Million
7	$100,000 - $300,000	1,530	272	$27.2 Million
8	$300,000 - $1,000,000	630	345	$34.5 Million

"Appropriate Protection Devices" that the authors suggest as being appropriate to the cost-effective cost range for each class. These are presented in Table 6.

Real-Time Information Systems

Several projects have been concerned with real time information systems for drivers. Heathington (31) used an attitudinal survey to evaluate driver attitudes towards a Freeway Driver Information System (FDIS). The research included an evaluation of the willingness of Chicago area drivers to pay for an information system on Chicago expressways, an evaluation of the likelihood of diversion to alternative routes when given specific information on freeway conditions, and an evaluation of the specific messages to be used for three levels of congestion. The transportation improvement considered most important by the Chicago drivers surveyed was the improvement of the riding surface on expressways. Also important was the provision of electronic signs giving information that Chicago drivers placed on real time information. With regards to the specific sign messages on the FDIS, the respondents indicated a preference for traffic information over non-traffic information at all levels of congestion. Therefore, even if no congestion exists, the drivers desired to be told that no congestion exists rather than be told nothing.

Hoff (32) looked at alternative methods of communicating with drivers. He examined different traffic information techniques which might be used to divert drivers around congested areas of the highway system. A questionnaire was developed to determine the preference of the driver for six alternative methods of communication. The ordered preference of Chicago drivers for methods of receiving information concerning freeway conditions was as follows:

1. changeable message sign,
2. symbolic map with arrows and streets,
3. symbolic map with arrows,
4. commercial radio,
5. roadside radio, and
6. experience.

TABLE 6. RELEVANT PROTECTION DEVICES FOR VARIOUS CLASSES OF GRADE CROSSINGS (Source: Ref. 9, p. 75)

Class	Warranted Expense	Number of Crossings	Appropriate Protection Devices
1	Under $300	65,100	Improved Passive Devices Enhanced Train Visibility
2	$300 - $1000	48,350	Improved Passive Advanced Warning; Train-beacon Reflectors
3	$1000 - $3000	32,540	Crossing-located Actuation; Conventional Signals (Marginally Feasible)
4	$3000 - $10,000	15,510	Crossing-located Systems Telemetry Actuation Minimal Cost Conventional Systems
5	$10,000 - $30,000	13,950	Conventional Systems of Improved Effectiveness--Gates, Uniform Warning Time
6	$30,000 - $100,000	3,480	Combinations of Above; More Complex Installations
7	$100,000 - $300,000	1,530	More Elaborate Installations; Interconnection with Highway Signals; Emphasis on Reduction of Motorist Delay
8	$300,000 - $1,000,000	630	Grade Separations and Sophisticated Traffic Control Systems; Typically Computer Controlled

Dudek and Jones (33) also evaluated real time visual displays for urban freeways. This research was directed toward the development of functional requirements for a real time freeway communication system for urban areas. The researchers felt that it was essential that the motoring public play a major role in establishing the functional requirements of the system, since the system must fulfill their needs. Their research was directed toward evaluating driver attitudes concerning the need for real time information, the potential use and response to real time information, driver preferences for mode of communication, the type of information desired, the priorities for the location of information, and driver comprehension of and preferences for visual displays. The surveyed Texas drivers were given three alternatives for real time information. The three alternatives were: 1) real time information, 2) additional guide signs, and 3) other (to be filled in by the respondent). The results indicate a preference for real-time information over additional guide signs. Only a small number of respondents filled in an alternative type of system. Their findings also indicated that Texas drivers preferred simple descriptive and color-coded displays over more complicated displays involving diagrams.

Dudek and Cummings (34) also evaluated alternative information systems. The main objective of this study was to investigate the application of commercial radio to freeway communication. As a part of this study alternative modes of communicating with drivers were evaluated using an attitudinal questionnaire. This survey of Texas drivers indicated the following order of preference for urban freeway information:

1. radio,
2. signs,
3. television, and
4. telephone.

They concluded, however, that no appreciable differences existed between the radio and sign modes. For all practical purposes, the ratio and sign modes of furnishing freeway information were considered equal.

This research concerning driver information systems indicates that improved driver communication is desired by drivers. A logical extension

of this research would be the application of the technology developed to other traffic situations. One extension is the evaluation of advanced warning systems for railroad grade crossing protection. Trabald and Prewitt (35) designed an Experimental Route Guidance System. The ERGS type system could be used to give drivers visual information inside vehicles concerning the hazard at railroad crossings and other highway hazards. A roadside radio communication system could also be used to provide audio warning messages at railroad crossings and other highway hazards (36). Finally, a changeable-message, advance warning sign could be used to provide advance warning at highway-railway grade crossings.

Urbanik (38) directed attention toward improving safety measures at individual crossings by improving the warning system. The effectiveness of basic information supplied to the motorist was determined. Attitudinal surveys were used in order to: 1) evaluate driver attitudes concerning the hazards at railraod grade crossings, 2) evaluate driver priorities for improving safety at railroad grade crossings, 3) evaluate warning systems for railroad grade crossings and 4) develop a typical design for a new advance warning system.

Significant results of the study were (38):

1. The respondents considered railroad grade crossings to be the most hazardous of the situations that were compared, i.e., more hazardous than signalized intersections, yield controlled intersections, cross roads and curves.
2. The improvement of the safety at railroad grade crossings was considered very important by all 259 respondents.
3. An overhead changeable message sign was the most preferred warning system at railroad grade crossings by all 259 respondents, (preferred to standard flashing lights, in-car audio message, in-car visual message and the present standard passive advance warning sign).

Also significant was the fact that the passive advance warning sign, currently standard, was the least preferred method of warning.

Changeable message signs are signs that can display one or more alternative message, e.g., variable speed signs, warning signs for bad weather or accidents, signs used to give freeway conditions, etc. The Chicago Area Expressway Surveillance Project conducted a substantial amount of research using variable message, electronic signs (39, 40, 41).

The electronic capabilities of these signs are currently sufficient to provide the desired warning messages with a high degree of reliability.

Changeable message signs have been used to a limited degree for several years. Maintenance difficulties, however, were common and the reliability of the signs was questionable.

Recently, electronic solid state concepts have evolved for changeable message displays that provide these systems with simple operation, lower operational cost and lower maintenance, i.e., improved reliability. The potential of these new systems which incorporate modern technology appears to be much greater than the "old" systems of a few years ago--certainly enough potential to be thoroughly investigated.

It was concluded by Urbanik (38) that the logical extension of his research was to evaluate all aspects of a variable message sign in a field installation, implementing the overhead, changeable message sign at high-speed, high-hazard grade crossings.

Data from a recent Indiana report (42) indicate that there are about 100 grade crossings in the state whose hazard index by the New Hampshire formula is high, some over 100,000, and additional protection is considered desirable (A hazard index of 4000 is considered sufficient to warrant additional protection.) Several crossings on this list should probably be considered for grade-separation structures if more money were available; however, Indiana cost estimates range from $300,000 for a two-lane roadway to $800,000 for separating a four-lane roadway (38). Improved advance warning systems should have the capability of improving the safety at such highway-railway grade crossings at a fraction of the cost of grade separations.

Responsibility for Grade Crossing Protection

A joint action group on grade crossing safety (FRA/FHWA) was formed in 1967 to investigate many facets of the problem. One area of study is the allocation of responsibility for grade crossing safety improvements between public and private agencies. The importance of this area must be emphasized because many times lack of agreement in this area delays or obstructs the improvement of grade-crossing protective

devices--particularly in the area of new or innovative devices and research programs to evaluate their effectiveness.

Although the railroads certainly carry the bulk of the financial burden for grade crossing protection, the trend is toward greater public participation. Hopkins points out (31):

> The growth of public involvement might not seem noteworthy to the casual observer. The basic function of crossing protection is, after all, to alert the motorist to a possible hazard - a responsibility normally assumed by governmental bodies for virtually all other potential dangers on highways. However, historical, technical, and legal considerations have traditionally lodged the primary burden of protection on the railroads. The movement away from that arrangement has arisen from a number of factors, which include the great increase in highway traffic, the diminished role of railroads as the predominant transportation mode, the impediment to efficient implementation of protection programs caused by diffusion of functions among numerous public and private bodies, and the ever greater degree to which public funds are involved.

Collier (43) notes the very significant change in the "old" concept of railroad responsibility. However, he also notes that states could legally and constitutionally require the railroads to bear the entire responsibility, which is what happened in a U. S. Supreme Court Case[1] as late as 1965. This issue is far from being completely resolved.

It has been previously mentioned that researchers have, primarily, had to work with accident data which were related to crossing parameters obtained from the accident reports and/or inventories. It has also been emphasized that the general quality of available data is poor, and most inventory data are questionable because of the changing nature of the parameters from year to year. A complete, nationwide inventory is essential to establish a comprehensive data base. The U. S. Department of Transportation and the railroad industry have begun (1974) to develop a centralized, comprehensive, national railroad-highway grade crossing data system (44, 45). The resulting computerized data base will be used as the main source of information for planning, implementing, and evaluating all improvement programs.

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[1] Florida East Coast Railway vs Martin County, Florida, 171 So. 2d. 837, Cert. den. by the U. S. Supreme Court in 382 U. S. 834 (1965).

Driver Reaction to Grade-Crossings

Accidents are symptoms of a problem. In spite of many projects based on the study of accident records, the problem is not well understood. There has been little research to determine the nature of the driver-grade crossing interaction. There have been only two research projects that have specifically addressed the problem of driver-grade crossing interaction. In addition, the Voorhee's Report (13) reviewed the "human factors" literature for driver characteristics that could be related to recommendations for improved protection systems at grade crossings.

Applications of Human Factors

The Voorhees Report (13) presented an extensive review of human factors, principles and considerations that could be applied to grade-crossing protective devices that would have more impact upon the driver and alert him to his responsibility to note the danger ahead. They present the problem as two-fold; 1) the driver must be aware that there is a crossing ahead and initiate certain perceptual and driving patterns and, 2) a secondary set of stimuli must alert the driver when a train is actually approaching the crossing. There has not been much effort to solve the "grade-crossing problem" by a human factors approach but a summary of pertinent considerations (as applied to drivers and their reaction to signs in general) should be helpful (13):

> ... in formulating not only specific solutions to specific problems, but also general principles of design and application to new systems to reduce accidents at highway-rail grade crossings.

The following recommendations were made for consideration in the design of improved grade crossing warning systems (13):

1. Make greater use of color and shape coding than has previously been the case.
2. Where possible, provide adequate illumination for each crossing.
3. Provide adequate advance warning for every crossing.

4. Make use of cross-modality stimulation; specifically, investigate the feasibility of rumble strips (tactual and auditory stimulation), horns (auditory stimulations), etc.

5. Provide redundant information, both by repetition of the message and by cross-modality stimulation.

6. Utilize the intermittent stimulation principle for all automatic signals.

7. Utilize automatic signals whenever possible; when not possible, provide unique, nonautomatic warnings with greater impact than the standard nonautomatic warning. That is, crossings without activated signals should be marked quite differently from those with activated signals so that the driver, upon approaching them, is made aware of the fact that it is his responsibility to determine whether or not a train is approaching.

8. Insure a minimum amount of distracting or irrelevant information by removing all extraneous messages from the immediate vicinity of the crossing.

9. Use warning devices of greater impact for isolated crossings.

10. Investigate the feasibility of providing the driver with prior information about crossing density and train traffic volume.

11. Incorporate some features of existing warning systems into any new and novel systems developed, to prevent adverse effects from negative transfer of old habits.

12. Provide the traffic engineer with warrants for crossing protection devices that are sufficiently flexible to permit him to utilize unique warning "packages" for unique crossing situations. A set of such warning packages, graded according to impact or attention value, could be part of the traffic engineer's arsenal.

Sanders (20, 3) investigated driver reaction to grade crossings. Inferences were drawn by recording driver-related variables at specific crossings rather than from accident reports (20, 3). Butcher (29) also investigated this problem. Sanders first report was primarily an attempt to provide the U. S. Department of Transportation with a data base that would reflect the behavior of motorists in the vicinity of grade crossings (20). One anticipated benefit was to supply information that could be used to determine values of vehicle delay for the time-delay portion of economic models or warrants.

The Speed Profile Study

"A Traffic Evaluator System" was used to instrument the highway at five points, roughly at 1,000 feet and 100 feet each side of the crossing and at the crossing. Each vehicle was tracked passing through the array, determining speed, lane change behavior, headway, wheelbase, and number of axles. Manual inputs were added to indicate vehicles which were required to stop, the actuation of protective devices, the arrival of trains and train speed. The result was a "stratified base" of over 40,000 vehicles from 26 crossings with parameters of urban/rural, two/four lane, high/low volume, and active/passive grade crossing protection (20).

All data that was analyzed were taken under dry pavement conditions. Other data were taken and included in the data base, but those data which were not comparable among all sites were not analyzed. As stated in the report (20):

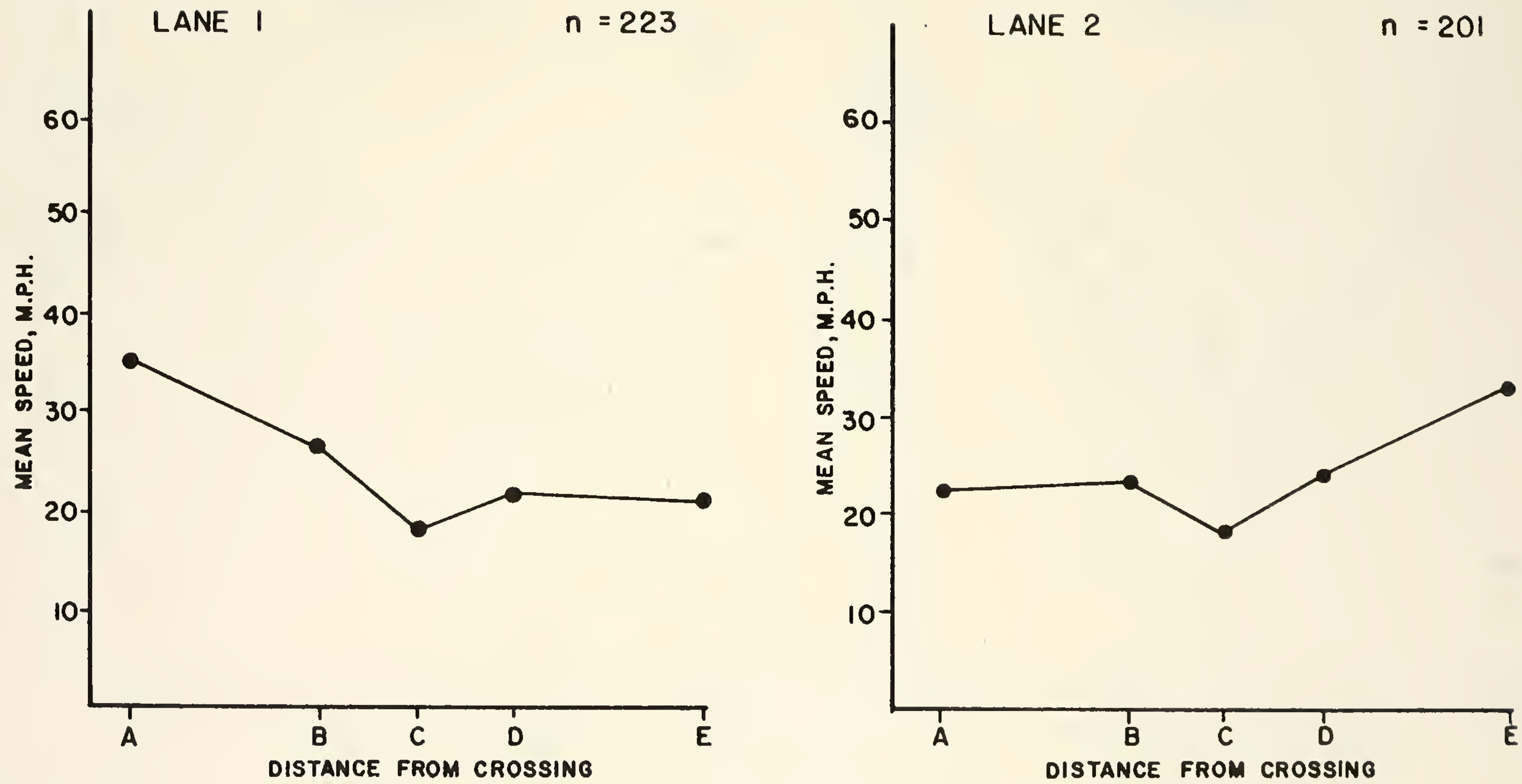
> Analysis of behavior during specific transition periods such as from day to night or dry pavement to snow could produce valuable results, therefore this data has been retained and is available for further study.

Speed profiles, limited to only passenger cars that did not stop (for train or any other reason), were drawn for each of the 26 crossings of the study. Passenger car average speed was plotted against distance from the crossing, which were variable distances depending upon where the contacts of the Traffic Evaluator sensors were placed on the pavement. A typical profile is shown as Figure 3.

A summary graph was prepared to illustrate the delay experienced by motorists by level of protection. This graph is shown as Figure 4. The mean car speed was converted to percentage of entry speed to "normalize" the effect of differences in normal free speeds at the 26 different crossings.

Significant conclusions included (20);

1. The reduction in speed measured from a large distance from the crossing, to the speed at the crossing, varied from 30 percent at smooth crossings to 70 percent at rough crossings.



DISTANCE KEY
A = -864'
B = -111'
C = 14'
D = 100'
E = 359'

DISTANCE KEY
A = -363'
B = -104'
C = 12'
D = 107'
E = 860'

SITE 8-11

FIGURE 3: SPEED PROFILES, PASSENGER CARS (Source: Ref 20)

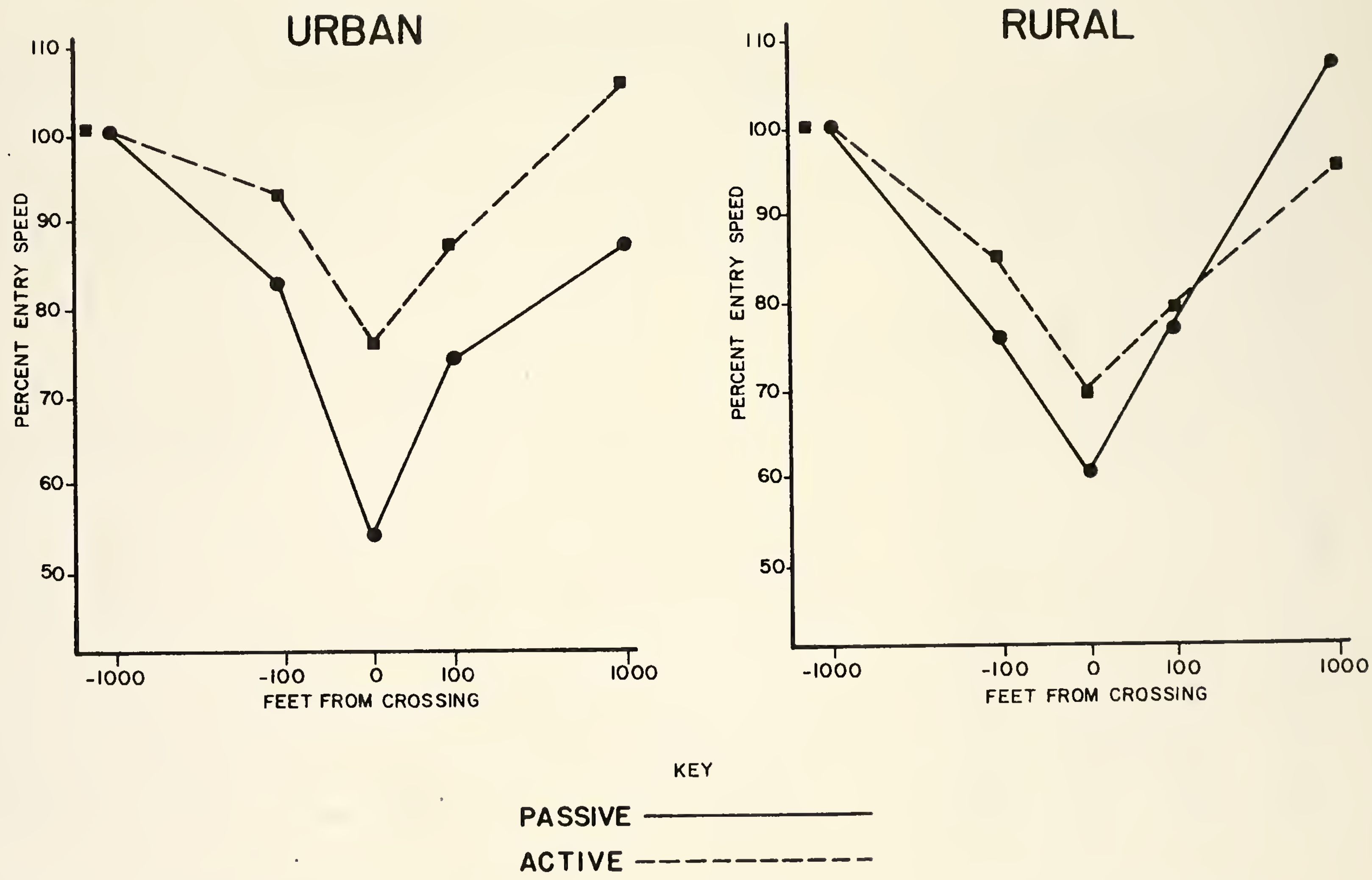


FIGURE 4: Speed profiles for all vehicles at two lane urban and rural crossings by protection type.
(Source: Ref. 20)

2. Evaluating the 45 cars that crossed an active crossing within one minute of a train arrival, 7 crossed while the signals were flashing. The reason appeared to be excessive warning time.
3. Legislation requiring buses to stop at all crossings appears to be unobserved and unenforced, based on 53 percent of the school buses and 88 percent of the commercial buses not stopping.
4. Speed reductions at sites having passive protection are both greater and occur sooner than at sites with active protection.
5. At rural sites, the difference in percent speed reduction for both types of protection are smaller than for urban.

The Human Factors Study

Sanders (3) reported on a human factors related study, undertaken to support a subsequent evaluation of alternative grade crossing accident countermeasures. This July 1973 report is one of the most recent and one of only three (3, 20, 29) that could be considered basic research on driver reaction to grade crossings, i.e., primarily field research of driver parameters. This report by Sanders is the only one that specifically attempts to relate human factor parameters from both the literature and roadside interviews to actual driver performance in the vicinity of crossings. Interviews taken past the crossing were matched with the driver's actual performance through the system.

The objectives of this study were many. Very briefly they covered the areas of providing guidelines for the development of countermeasure concepts, selecting countermeasures for field testing, evaluation of the countermeasures and experimental design and procedures. Three data collection procedures were used; namely, the traffic evaluator system, time lapse photography, and motorist response to questionnaires within the inference space of the study. It was concluded that driver looking behavior,[1] crossing speed and speed reduction were sufficient and valid

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[1] Looking behavior could only be easily evaluated at crossings with restricted sight distance and where drivers tended to make an obvious head movement as soon as they were "past the restriction." Head movement could not generally be clearly observed where sight distance was unrestricted. Thus, this is a restricted parameter.

measures of performance to evaluate changes in protective systems. The Traffic Evaluator road switch placements are shown in Figure 5a. These placements were closer at distances near the crossing in an attempt to equalize travel time between contacts as vehicles slowed for the crossing. Figure 5b shows typical speed profiles at several sets of crossings.

To meet the many, diverse objectives of their study (3), a four-phase approach was used. Phase I was a review of a selected sample of accidents. Phase II was the establishment of human factor norms with respect to driver knowledge, attitude, and behavior to serve as standards of comparison of "before" and "after" studies of specific grade crossing sites and provided measures of effectiveness. Phase III was a "pilot" validation study to test the standards and measures of effectiveness of the previous phase. Phase IV was the experimental design for planning large scale experimentation.

In the attempt to find a particular subgroup of high-risk grade crossing accident drivers characterized on psychophysiological dimensions, none was found. The most significant finding was a demonstrated degradation with age.

Installation of flashing lights on each side of a standard, advance warning sign was evaluated to field test the parameters: 1) speed change and 2) looking behavior. Data were taken "before" and "after," i.e., the three conditions of 1) existing protection 2) dim flashers and 3) bright flashers. A plot showing the speed change is shown in Figure 6a. A "t" test of the means showed that there were significant differences before and after mean values of both speeds and looking behavior.

A higher percentage of drivers stopped for both the flashers than the existing protection as shown in Figure 6b. Two conclusions were drawn: 1) The modification caused a short term modification of behavior and 2) The parameters speed and looking behavior are sufficiently sensitive to that change to indicate a significant result.

Another parameter evaluated was "zone of maximum deceleration." Mean deceleration was calculated for each of five segments of approach between the traffic evaluator contacts.

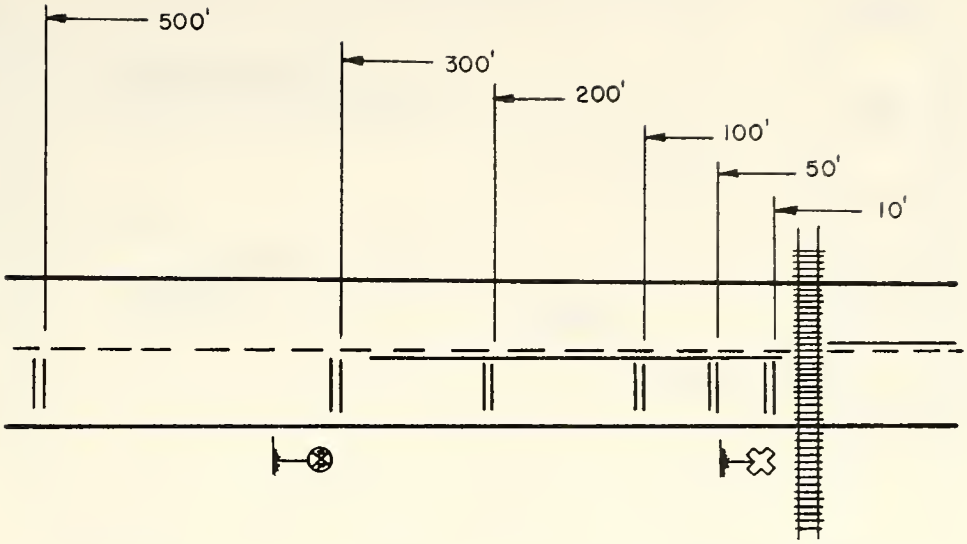

FIGURE 5a Placement of vehicle sensors in advance of grade crossings. (Ref. 3, p. 5-8)

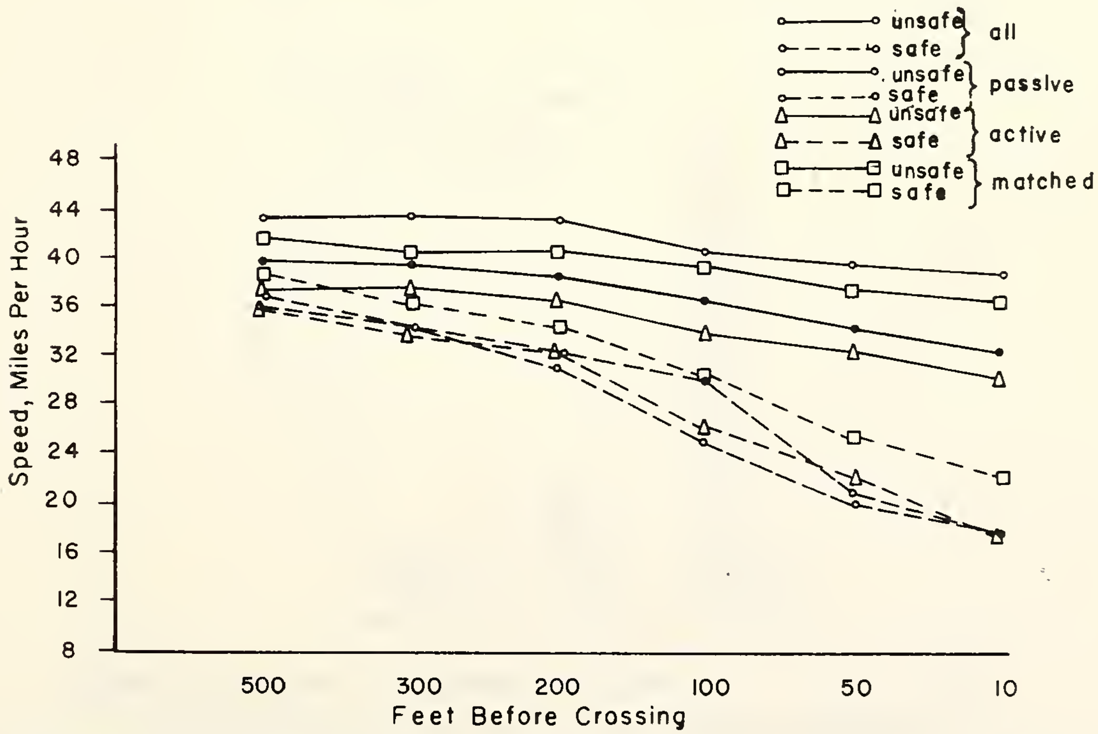

FIGURE 5b Speed profiles of drivers for four sets of crossings divided by the most safe and least safe index quartile. (Ref. 3, p. 7-10)

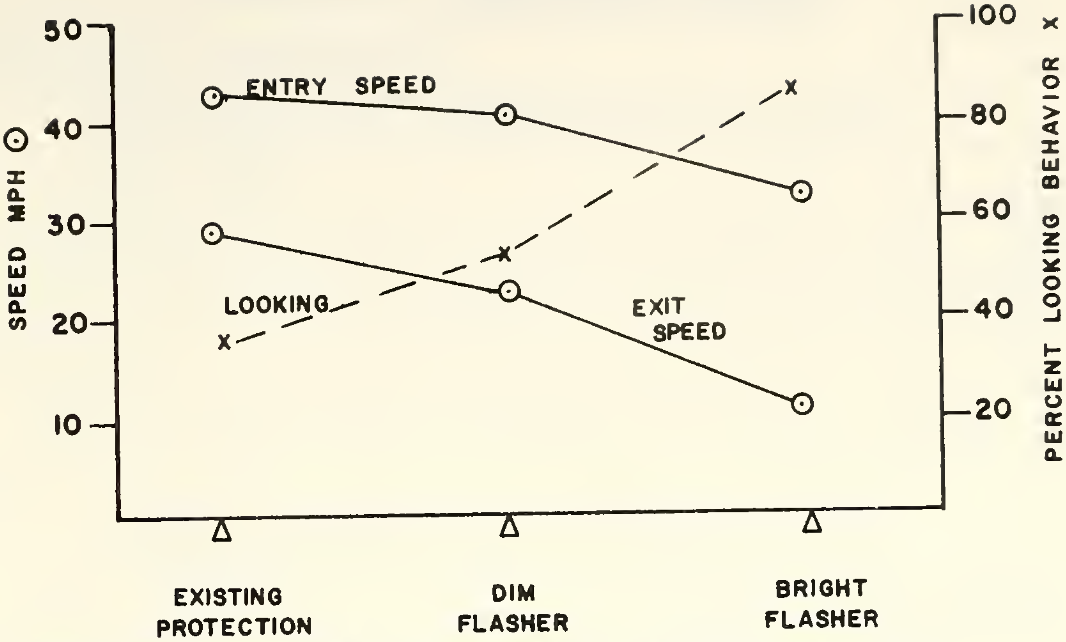

FIGURE 6a Comparisons of measures for entry speeds (430') and exit speeds (10') and looking behavior for three conditions of protection. (Ref. 3, p 4-13)

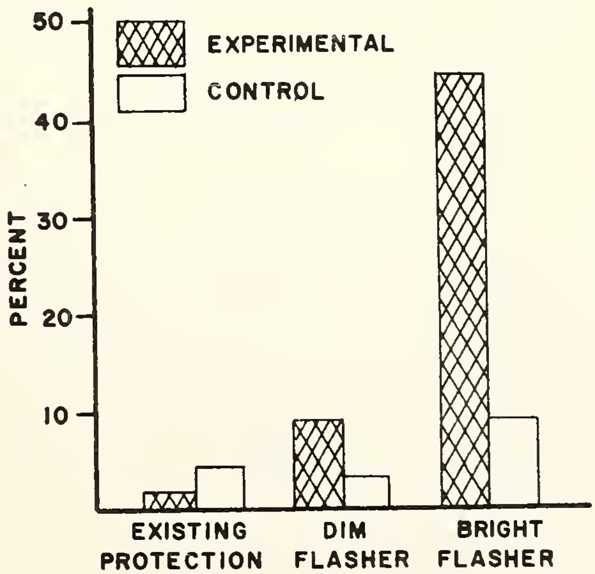

FIGURE 6b Percent of drivers who stopped at the crossing for both directions under three experimental conditions.

$$\text{Deceleration} = \frac{\text{Speed change per segment}}{\text{Time to travel segment}}$$

It was stated in the report (3):

> The magnitude of the maximum deceleration correlates highly with the percent speed reduction (over 0.62 in all cases).

The maximum deceleration was found to occur about 45 feet from the crossing leading Sanders to conclude that the population waits as long as possible before slowing to the speed at which they desire to cross the tracks (3).

Another parameter that was examined by Sanders was critical distance, that is (3):

> as a vehicle approaches the grade crossing along the mean speed profile, there is a point at which he cannot stop his car short of the tracks

If a train is approaching at this point, the driver's only alternative to a collision is to beat the train to the crossing.

Finally, in regard to the above four parameters, a "behavior index of safety" was developed.

Safety Index = looking + speed reduction
- maximum deceleration point
- critical distance

Because of large differences in relative magnitude the above parameters were normalized, i.e. (3),

> the mean value within each site for each measure was subtracted from the measure to scale it to a mean of zero, and then divided by the site standard deviation of the measure to normalize the value

It was concluded that the contribution of protection improvement (countermeasure) can be determined at a specific site by a before and after study using only (as a minimum) vehicle speed and looking behavior.

Evaluation of the Literature

It is clear from studying the literature that there has been little research directed explicitly toward driver reaction to grade crossing systems. This is true both in regard to systems as a whole and to a particular system. The three that were so directed (3, 20, 29) showed

that parameters to evaluate the effectiveness or change in effectiveness at a grade crossing are illusive. Sanders (20) concluded that speed and looking behavior were sufficient but speed is not believed to be a major factor in grade crossing accidents and looking behavior can only be measured under restricted conditions.

In the past few years, there has been considerable research directed toward solving the "grade crossing problem." Review of this research reveals that it has been almost exclusively "accident record" based. The drawbacks and weaknesses in accident data have been pointed out. These are in addition to the obvious weakness of time, i.e., at an individual crossing one cannot judge improvement effectiveness with accident history over a short time period.

Numbers of accidents can be predicted with some degree of success according to groups of crossings and by protection type. However, at a specific crossing this type of analysis has little validity. Thousands of grade crossings apparently do not warrant gates, or even flashers, or if they do money is not available, and yet people are killed. There is a need, then, for parameters to effectively evaluate lower-cost systems to more effectively alert the potential victim.

Human factors research to identify this potential victim is lacking in the literature. The Voorhees Report (13) reviewed driver characteristics and made recommendations for better warning signs. Sanders (3) attempted to apply human factors to selecting improvement strategies and then field evaluated a system so selected using the approach speed and looking behavior parameters with some success. However, his human factors approach did not pinpoint a high-risk subgroup of drivers, perhaps there is none, except as affected severely by advanced age.

The above approaches, particularly the field evaluations, are valuable contributions, however there are weaknesses. For example, one has to assume that lower mean approach speeds means less accidents. Also, that the driver who turns his head sees, comprehends and properly evaluates the conditions. In addition there is no way to equate speed or speed change and/or percent of "looking drivers" to accident prediction, probability of occurrence, or predicted change, particularly in the long run.

In regard to Sanders (3) field test that had great short-term effect on reducing speed, increasing looking, and causing drivers to stop (refer to Figures 7 and 8) one caution is in order. This writer believes the results are most likely because the driver "feels" this flasher is train activated. In other words, he had been "fooled" into believing a train was approaching. In the long run this type of improvement approach could be dangerous. This, and other facets of the problem need to be further studied.

In summary, little is really known regarding driver reaction to different grade crossing systems or even to the same system under varying conditions. Parameters to measure reactions are unproven, particularly as to their effect on safety. Nevertheless, research in these areas must continue to better understand the problems and not just the symptons - accidents.

CHAPTER 3: PURPOSE AND SCOPE

In early 1972, the Indiana State Highway Commission sought an immediate solution for a grade-crossing where pressure by the press and local citizens was mounting because of a high accident and death record. This location was the crossing of U. S. 31, a four-lane, 65 mph (posted) highway, and Norfolk and Western (N & W) tracks near Goldsmith, Indiana. A three phase research proposal was initially prepared:

1. Install traffic signal type overhead red flashers on cantilever arms over the highway at the crossing, activated with the standard railroad flashers.
2. Install an overhead luminaire to illuminate the crossing during passage of a train, activated concurrently with the overhead flashers.
3. Install automatic gates.

The first two systems were to be installed and maintained by the Indiana State Highway Commission with no railroad participation in the cost; however, N & W Railroad was asked to provide a relay switch to activate them concurrently with the railroad flashers. The automatic gates were to be negotiated and installed through the usual State-Railraod procedures for upgrading protection at any grade crossing. It was planned to obtain data after each improvement was made, in addition to the initial data base or "before" data. The Highway Commission engineers recognized that too little is known about the real causes of accidents such as these, and also recognized that no matter what improvement program was undertaken they had no measure of effectiveness to determine how much they had improved the situation.

The primary purpose of the research, then, was to determine quantitatively the degree of effectiveness of each of the planned improvements and to develop methodology to evaluate the effectiveness of similar improvements at other grade crossings. This included the development of simple techniques capable of measuring parameters

whose characteristics were found to be related to the degree or quality of improvement.

Spot speed at specific points on the approaches was selected as the parameter most likely to be related to the degree of improvement. Such speeds taken at several points of approaching drivers provided an "approach-speed profile" for each driver. Inferences from the evaluation of these approach-speed profiles and changes in them due to each improvement (or due to change of conditions within a particular system) were used to evaluate the effectiveness of the improvements.

A secondary purpose was to evaluate speed data as a measure of drivers' reactions and characteristics to a high-speed rural, grade crossing.

It was decided to use a 16 mm movie camera to obtain the speed data quickly and cheaply. Details of the system are presented in Chapter 4.

During the period of time that the data collection system at the Goldsmith grade crossing was developed and while the before (phase I) data collection was in progress (Spring 1972), serious administrative problems developed on the overall project. The original concept of a 3-phase improvement program had to be scrapped due to inability to negotiate necessary State-Railroad agreements. Ultimately (May 1973), only one improvement, the automatic gate system, was installed at the grade crossing. The primary purpose of the research then became the analysis of the effect of the automatic gate system and driver reaction to it and other site conditions.

Because of the one year delay between the collection of the phase I data and the installation of automatic gates, "before" data were analyzed and reported by Butcher as part of an Interim Report, "Evaluation of Safety Improvements at Highway-Railway Grade Crossings." This report on the phase I portion of this project is summarized in Chapter 4.

After the gates were installed, a three week delay was allowed for local drivers to become accustomed to the new system. Data collection for the after condition (phase II) then commenced. At the end of data

collection for phase II, an analysis was made of the complete before and after data sets.

Additional speed profile data were available from another research study, an FHWA research project previously summarized in the literature review and referred to as the Sanders study (20). It was implied by Sanders that this data base contained valuable, unanalyzed raw data on motorists' approach speed profiles under varying conditions. The data consequently were secured from FHWA and analyzed in an attempt to supplement the Goldsmith analysis. This analysis is reported in Chapter 6.

Specific Objectives

The specific objectives of the research at the Goldsmith grade crossing were as follows:

1. To determine the effectiveness of the automatic gate system by an analysis of the before and after approach speed profiles and related parameters.
2. To evaluate speed and related parameters (such as, deceleration rates, above pace speeds, high speeds, speed distributions, etc.) as sensitive measures of significant changes in effectiveness.
3. To evaluate site conditions and accident history with the danger associated with this crossing and with driver approach speeds and characteristics.
4. To evaluate the effectiveness of the selected filming system for data collection.

CHAPTER 4: SUMMARY OF INTERIM REPORT ON THE GOLDSMITH GRADE CROSSING[1]

Orientation of the Goldsmith Crossing

The crossing is located approximately one mile north of the intersection of U. S. 31 and State Road 28, which is controlled by traffic light signals. U. S. 31 is a four-lane divided highway, with north-south orientation over level terrain. Lane widths are twelve feet and the median is 66 feet in width. Posted speed is 65 miles per hour, and the 85th and 15th percentile speeds are 66 and 50 respectively. The highway ADT is approximately 10,000 vehicles.

The railroad track is a single main line track oriented at 90° with the highway, in an east west direction. There are about six freight trains (no passenger trains) operated on an "as needed" basis with a speed range from 20 to 60 miles per hour. The track is level and on tangent for at least a mile in each direction from the highway and elevated above the surrounding fields each side of the crossing. The crossing itself was relatively smooth at the beginning of the project. However, during the after phase of the project, the crossing was completely renovated as part of a highway resurfacing project on U. S. 31.

County Road 100 S parallels the rail tracks on their south side. It is gravel surfaced and carries very light volumes. Its intersection with U. S. 31 is controlled by stop signs. Yield signs are placed in the crossover of the median between the U. S. 31 approaches. Separate railroad flashers are directed toward traffic entering U. S. 31 from this road. The layout is shown in Figure 7.

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[1] Summary paraphrased from Butcher (29), Interim Report.

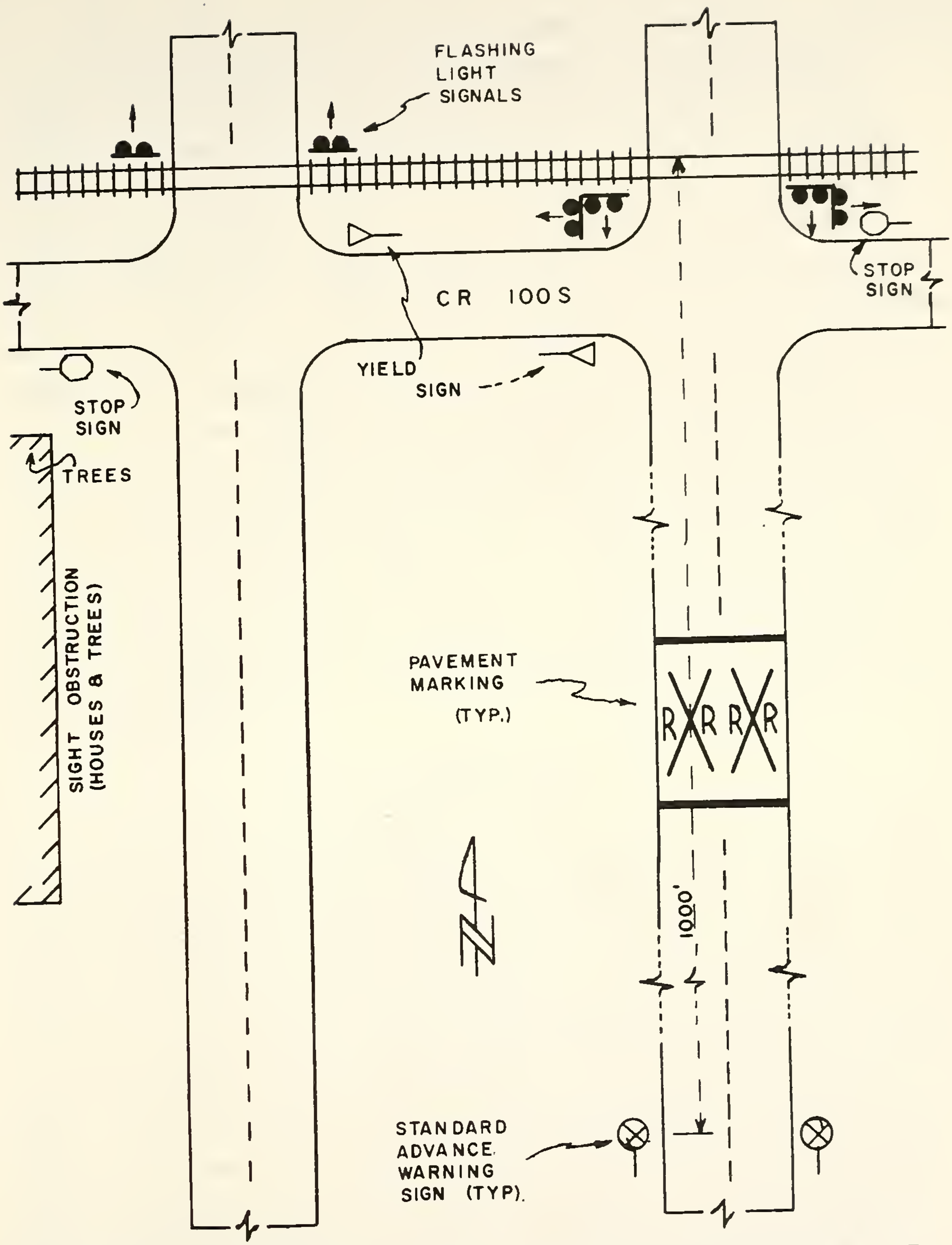

FIGURE 7: SCHEMATIC VIEW OF THE U.S. 31-N&W RR GRADE CROSSING SITE NEAR TIPTON, INDIANA (BEFORE IMPROVEMENT) (REF. 29, p. 56)

Sight distance along the railroad track for approaching motorists is relatively unobstructed in three quadrants. In the southwest quadrant sight distance of a train is restricted to about 200 feet, because of a woods, for northbound motorists. For such a northbound motorist, an eastbound train is not clearly visible at the time the signals are activated. When the crop in the southeast quadrant is corn, an obstruction to sight distance could also exist there for a portion of the year. In the northwest quadrant, the field is depressed enough below the road and track that sight distance over crops is unobstructed. However, the wooded area south of and parallel to the track west of the highway presents for southbound traffic a poor background, i.e., a dark train against the dark background creates little contrast and may have the effect of camouflaging a train. From personal observation the author is of the opinion that under certain conditions, this condition may be serious, perhaps even worse than a sight obstruction. A similar condition exists to the east of the crossing, although the trees do not closely parallel the track, but are in the background.[1]

Accident Record

In spite of all the apparent safe features of the site, such as, level terrain, good sight distance, active protection, no-skew, no curved alignment, etc., the accident record here has been one of the worst in the State of Indiana, particularly in the last few years. There have been a total of 38 accidents in 15½ years, including 8 fatal accidents and 14 personal injury accidents which resulted in 13 deaths (all since March 1965) and 26 injuries. Also, as can be seen from Tables 7 and 8, almost all of the 38 total accidents at this crossing have occurred during daylight hours with clear skies and dry pavements. Eight of the 12 train-vehicle collisions occurred on the southbound approach where a vehicle approaching the crossing has unobstructed sight distance down the track to the west of ½ mile or more during the

[1] This can be seen in Figures 15 and 16.

TABLE 7. SUMMARY OF ACCIDENTS AT THE U. S. 31-N & W RR CROSSING SITE FOR THE 15½-YEAR PERIOD, JANUARY 1, 1957 THROUGH JULY 1, 1972. (Ref. 29, p. 60)

Accident Description:	Total Accidents	38
	Fatal Accidents	8
	Personal Injury Accidents	14
	Property Damage Accidents	16
Casualties:	Total Fatalities	13
	Total Personal Injuries	26
Day of Occurrence:	Weekday	30
	Saturday or Sunday	8
Light Conditions:	Daylight	29
	Darkness	8
	Dawn/Dusk	1
Vehicle Direction:	Northbound	16
	Southbound	22
Pavement Condition:	Dry	31
	Wet	5
	Ice/Snow	2
Weather Condition:	Clear	34
	Raining	1
	Snowing	3
Type of Accident:	Rear End	17
	Right Angle	2
	Sideswipe	2
	Car Hit Train	7
	Train Hit Car	5
	Other	5
Train Involvement:	Train Present and Involved	12
	Train Present, Not Involved	12
	Train Not Present	14
Accidents Involving Movements From or Onto CR 100S, but not the Crossing *per se*		4

TABLE 8. SUMMARY OF TRAIN INVOLVED ACCIDENTS AT THE U. S. 31-N & W RR CROSSING SITE FOR THE 15½-YEAR PERIOD, JANUARY 1, 1957 THROUGH JULY 1, 1972. (Ref. 29, p. 61)

Date	Day of Week	Light Condition	Pavement Condition	Weather Condition	Train Speed, mph	Train Direction	Vehicle Speed, mph	Vehicle Direction	Vehicle Struck Train	Train Struck Vehicle	No. Persons Killed	No. Persons Injured	Driver Age	Driver Sex
3/ 5 /65	Fri.	Daylt.	Wet	Clear	45	EB	50	NB		XXX	1	0	65	M
4/16/65	Fri.	Daylt.	Dry	Clear	58	EB	?	NB		XXX	1	1	61	M
9/28/65	Tue.	Daylt.	Dry	Clear	60	EB	60	NB	XXX		2	0	53	M
12/24/66	Sat.	Daylt.	Dry	Clear	40	EB	60	SB	XXX		0	1	76	M
12/25/66	Sun.	Daylt.	Dry	Clear	40	WB	55	SB	XXX		0	1	55	M
5/25/66	Sat.	Darkns.	Dry	Clear	60	WB	60	SB	XXX		1	1	22	M
1/24/69	Fri.	Daylt.	Wet	Snow	60	EB	65	SB		XXX	0	0	39	M
3/ 6 /70	Fri.	Daylt.	Dry	Clear	53	EB	75	SB	XXX		0	1	47	M
2/12/71	Fri.	Daylt.	Ice	Rain	?	?	?	SB	XXX		0	1	46	F
9/ 5 /71	Sun.	Daylt.	Dry	Clear	54	EB	60	SB	XXX		4	0	73	M
10/13/71	Wed.	Daylt.	Dry	Clear	50	WB	?	SB		XXX	1	0	80	M
10/29/71	Fri.	Daylt.	Dry	Clear	51	WB	65	SB		XXX	2	0	71	M

entire last ½ mile of his approach to the crossing and almost as much to the east. A complete analysis of the accident record will be made in Chapter 5.

The Data Collection System

The data required to determine driver reaction were spot speeds at sufficient locations to develop a speed profile as a vehicle approached the grade crossing. With these data the vehicle's rate of deceleration could be calculated and analyzed, and the locations where the driver made noticeable speed cahnges could be determined.

As the Goldsmith project was initially conceived, there were a number of constraints on the development of the data collection system, primarily related to time. Data collection had to be carried out without delaying any improvements that were to be made; thus, it had to be begun at the earliest possible date. There were also budget limitations, that is, large sums of money were not available. Conception and design of the system were limited to equipment that was either on hand or available quickly and at nominal cost, as well as one that would not be apparent to the average motorist. These constraints led to the implementation of a photographic system employing a 16 mm variable speed movie camera that could be rented from the Audio-Visual Department.

A camera setup position was determined for each approach approximately 750 feet from the roadway and 600 feet from the railway track. Markers were placed in pairs, parallel to the highway, such that each pair intersected the line of sight from the camera to a 55 foot speed "trap." By filming a vehicle at a set film speed, and counting the frames of the developed film that it took a vehicle to traverse a pair of markers, frame counts were converted to the average speed of the vehicle between marker pairs. This average speed of a vehicle over a 55-foot trap length was assumed to be the vehicle's spot speed at the center of the trap. The photographing setup is shown in Figure 8.

Each marker was a two-by-two-foot square of sheet metal supported in a diamond configuration on a steel post. The markers were placed at a height so as to be silhouetted against passing vehicles when

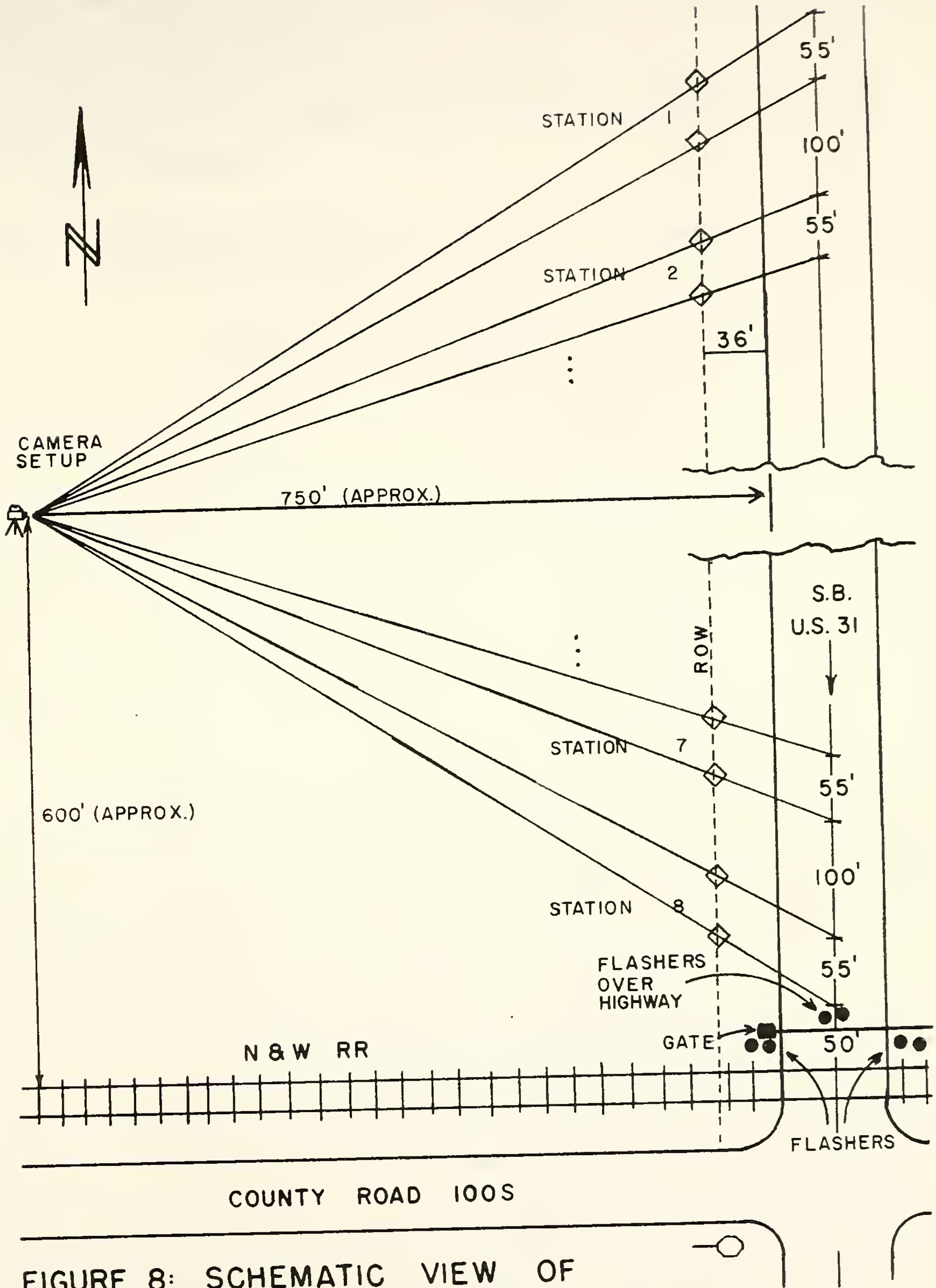

FIGURE 8: SCHEMATIC VIEW OF MARKER PLACEMENT AND CAMERA SETUP POSITION (REF. 29 p. 67)

viewed from the observation point. A close-up of a typical trap with markers is shown in Figure 9.

Table 9 lists the eight station designations and their distance from the nearest track to the center of trap, the point at which the spot speed was measured.

TABLE 9. NUMBERS AND LOCATIONS FOR THE EIGHT SPOT SPEED STATIONS ON EACH APPROACH

Station Number	Distance from Nearest Track to Center of Trap
1	1162.5
2	1007.5
3	852.5
4	697.5
5	542.5
6	387.5
7	232.5
8	77.5

Markers were painted white on the side facing the camera and green on the side facing the highway. The posts were also painted green. This was an effort to make the markers as inconspicuous as possible to passing motorists and as visible as possible on the film. The camera set-up position was assumed to be far enough off the roadway such that no camouflage was necessary.

The photographic equipment was leased from the Audio-Visual Department of Purdue University. The camera was a 16 mm Ariflex-M motion picture camera, powered by an eight volt rechargeable battery and having a 400-foot film capacity. A 12-120 mm Augeneux zoom lens was used in order to provide close-up views of the vehicles over the required distance. The lens had to be near full zoom in order to accurately count the frames that were shot while following a vehicle between marker pairs. More correctly stated, the problem was less one of following a particular vehicle than it was determining exactly when the vehicle

FIGURE 9. SOUTHBOUND CAR ENTERING TRAP 8

lined up with the markers at the trap end points. That is, the magnification of the lens was necessary to pinpoint a marker against a vehicle such as illustrated by still photography in Figure 9.

The camera was driven by a variable-speed electric motor, equipped with a tachometer calibrated in frames per second. After an initial check on film speed, made by photographing a stop watch, indicated that the tachometer was accurate, the speed indicated by the tachometer was thereafter assumed to remain accurate.

After the films were developed they were viewed by the use of an Industrialist sto-motion projector, modified (commercially) from a Kodak Analyst projector. Each subject vehicle was followed through each of the eight speed traps. The number of movie frames it took the vehicle to traverse between the two markers constituting a trap was recorded to the nearest one-half of a frame. This number of frames was subsequently converted to miles per hour by the formula:

$$\text{mph} = \frac{(24\ \text{frames/sec})\ (3600\ \text{sec/hr})\ (55\ \text{feet})}{(5280\ \text{feet/mile})\ (\text{number of frames})}$$

which reduces to:

$$\text{mph} = \frac{900}{\text{number of frames}}$$

An error of one-half of a frame in estimating the total number of frames would result in an error of slightly greater than one mile per hour for speeds lower than 50 mph and a slightly larger error for speeds over 50 mph.

Analysis of Phase I Data

All data were collected during daylight hours under conditions of clear visibility. In the experimental design, it was decided to place all vehicles into four basic categories; 1) "free flow vehicles," 2) "first unobstructed vehicles," 3) "first obstructed vehicles," and 4) "following vehicles." These categories are defined below:

A "free flow vehicle" is defined as one in which the motorist travelled through the approach with no train present and no other vehicle between him and the crossing. In this condition

there was no stimulus other than the existence of the crossing itself and its unactivated devices.

A "first unobstructed vehicle" is defined as one driven by the motorist who entered the first speed trap while the signals were flashing but chose to go through the crossing without stopping, ahead of the train, which was not yet at the crossing. The added stimulus was that of the activated flashers and possibly sighting of the approach train.

A "first obstructed vehicle" is defined as one in which the motorist entered the first speed trap with the flashers activated and a train already across, or about to cross, the highway. The added stimulus in this case was the train across or close to the highway.

A "following vehicle" is defined as one in which the motorist entered the first speed trap under conditions of signal activation, a train across the highway and at least one other vehicle already stopped at the crossing. The added stimulus in this case was the stopped vehicle(s) on the highway.

Sampling Procedure

In order to minimize the influence of stimuli other than the prevailing conditions at the crossing, a free-flow vehicle was sampled only if there were no other moving vehicles between it and the crossing as it entered the first speed trap.

Basis of Comparison

As one basis for comparison of driver performance in each of the four vehicle categories, deceleration rates were calculated for each vehicle between each of the eight speed traps. These deceleration rates were placed into five classifications as derived from guidelines in The Traffic Engineering Handbook. The classes were:

Class 1 - "comfortable"	8 ft/sec/sec or less
Class 2 - "uncomfortable"	>8 ft/sec/sec through 11 ft/sec/sec
Class 3 - "undesirable"	>11 ft/sec/sec through 14 ft/sec/sec
Class 4 - "very-uncomfortable"	>14 ft/sec/sec through 20 ft/sec/sec
Class 5 - "emergency"	>20 ft/sec/sec

Another method of comparison was to make statistical tests on the differences between mean entry speeds in the first trap for all categories of vehicles on each approach. In particular, tests were made for significant differences of the mean and variances of: 1) free flow car vs. first unobstructed car, 2) free flow car vs. first obstructed car, 3) free flow car vs. following car, 4) first unobstructed car vs. first obstructed car, 5) first unobstructed car vs. following car and 6) first obstructed car vs. following car.

Speeds at the other traps for each category were also plotted, and compared as a percentage of entry speed for each group. These speed profiles were the third primary measure of driver reaction to the crossing protection system.

Conclusions: Phase I Data

Data Collection

First, it was concluded that the photographic data collection and reduction process was adequate for determining speed profiles and rates of vehicular deceleration at highway-railway grade crossings. Many grade crossings and other situations would be suitable for application of this technique. In terms of being "quick, cheap and effective," it proved to be especially advantageous.

Approach Speeds

Analysis of the data showed that motorists approaching this crossing reacted differently depending upon the prevailing conditions (stimuli) at the crossing. As a first step in the analysis, statistical tests showed that there was a significant difference between mean approach speeds from the south and the north. It was hypothesized that this was because of the traffic signal one mile south of the crossing and possibly because northbound drivers were more cautious due to poor sight distance to the west. Data were analyzed separately for each approach; however, except for slightly reduced mean speeds, results were similar.

Drivers who entered the approach when the signals were activated without a train immediately present (first unobstructed vehicles) entered the approach at "free-flow" speeds and did not begin slowing their vehicles until relatively close to the crossing. Motorists entering the approach with the added stimulus of a train across, or about to cross, the road (first obstructed vehicles) slowed earlier and decelerated more gradually. Motorists approaching behind vehicles which were already stopped ahead, entered even more slowly. Thus, earlier deceleration of approaching motorists appeared to be a direct function of the amount of added stimuli present. It was hypothesized that the generally-accepted, superior effectiveness of automatic gates was due to the added stimulus of the gates across the highway, perhaps simulating, to the approaching driver, a vehicle stopped in the roadway.

Numerous tables and graphs showing the comparisons of mean entry speeds for all categories of southbound and northbound vehicles and plots of the speed profiles of each category on the approaches are presented in the Interim Report.

Deceleration Rates

An analysis of 3640 vehicle deceleration rates, seven for each vehicle, showed that only 20 of them, contributed by 13 vehicles, were higher than the comfortable range. These higher rates of deceleration occurred in free flow cars, first unobstructed cars or first obstructed cars and all occurred between 700 and 230 feet of the crossing. Two probable causes are: 1) extremely high approach speed or 2) not becoming immediately aware of the existence of the crossing or approaching train. Whatever the cause, these 13 drivers formed the group of drivers who came close to being involved in a grade crossing accident.

A reduction in the number of such incidents may be possible by providing warning devices with more impact on drivers. Also, reduction in the number, or percentage, or such incidents may be an important indication of the effectiveness of grade crossing protective devices.

Summary

The conclusions of Phase I are presented below as they appear in the Interim Report (29):

1. The photographic data collection and reduction process developed as a part of this research was relatively inexpensive and quickly implemented, and was effective in determining speed profiles and rates of deceleration for vehicles approaching a highway-railway grade crossing. It should have further application for similar studies where terrain, sight distances and climatic conditions permit.

2. It appears that grade crossing accidents involve singularly inattentive or distracted motorists, based upon the fact that the groups of drivers in the several categories studied could not be distinguished by differences in deceleration rates between the categories.

3. Motorists approaching the grade crossing in this research reacted differently depending upon the prevailing conditions at the crossing. Drivers who entered the approach when the signals were activated without a train immediately present did not begin slowing their vehicles until relatively close to the crossing. Motorists viewing the added stimulus of a train across the road, or close to the crossing, slowed their vehicles earlier, and decelerated more gradually. Motorists approaching behind vehicles which were already stopped for a train entered even more slowly. Thus, each of these added stimuli at the crossing carried with it a corresponding earlier and more gradual deceleration by the affected motorists. This may explain why automatic crossing gates, which present a stimulus similar to that of a stopped vehicle, have proved to be the most effective type of standard crossing protection device.

4. Only 20 of the 3640 vehicle deceleration rates calculated in this study were higher than the comfortable range. Thirteen vehicles contributed these 20 high rates. These vehicles were from the categories of free flow cars, first unobstructed cars or first obstructed cars. The abnormal ranges generally occurred between 700 to 230 feet from the crossing. It is probably that some of these excessive rates were caused by the very high approach speeds of some of these vehicles, but it is also

possible that some of it was found that actions of groups of motorists in several categories, based upon prevailing crossing conditions, could not be distinguished on the basis of deceleration rates, thus indicating that drivers involved in grade crossing accidents are singularly inattentive or distracted. It was also determined that drivers approaching the crossing under progressively greater stimulus as to the hazard involved entered the approach at correspondingly slower speeds and decelerated more gradually.

CHAPTER 5: DRIVER REACTION TO A HIGH-SPEED RURAL GRADE CROSSING

Data Collection Phase II

The automatic gates were installed at the Goldsmith grade crossing in April 1973. After a three-week period to allow local drivers to adjust to the new system, phase II, the "after" phase of the research project was begun. Care was taken to reproduce data collection procedures and techniques that had been used during phase I. The same equipment was used.

Condition Differences Between Phases

In the second phase, with automatic gates that activated at a uniform time prior to the train's arrival, there would be no category of approach vehicles that fit the definition of "first unobstructed" of Phase I. It was not initially clear what other differences in approach vehicle categories there might be. With this in mind notes were taken with sufficient detail so that vehicle approach conditions would be clear when the film was reviewed. These notes were printed on sheets of paper with a felt pen and photographed immediately after an occurrence. Thus, after data reduction, grouping could be analyzed.

The Marquardt train speed predictor which had been installed with the gates created one minor "problem" that was not present during Phase I. During Phase I, the signals were activated at a given point on the track regardless of train speed. It was possible for the camera operator to note this point, know exactly when the signal would be activated and know when to start looking for entering vehicles. With the Marquardt predictor, there was no such "point" since train location at activation depended on train speed. Therefore, the operator

had to pay close attention to the signal itself before picking up the first entering vehicle.

The Marquardt system resulted in possibly one variable that was not present in Phase I and whose affect in Phase II can only be estimated. That is, slow trains were relatively close to the crossing before signals were activated. Because of the clear sight distances of approximately ½ mile in three quadrants, a motorist could see a slow train several seconds before the train activated the signals. Whether a motorist really did notice such a train, and what affect it may have had on his approach speed before signal activation, could not be positively determined.

Collection Time Period

Data collection progressed throughout the summer of 1973. There was no way to obtain a railroad schedule that was accurate enough to be of value. The plan adopted was to drive to the site early, set up and wait. On a few days during phase II no trains approached during the waiting period. On a few occasions there were no vehicles which approached the crossing when a train crossed. As a result several days were required to obtain adequate data.

Weekends, including Fridays, were excluded as not being typical. The collection process extended from mid-May until mid-August. It was assumed that traffic characteristics remained constant over this period. Observations at the site gave no evidence to the contrary.

Data Reduction

Vehicle Categories

After the film was developed it was run through the same projector used to reduce the phase I data to frame counts, as described previously.

The Interim Report defined two categories of "first" vehicles, namely, first unobstructed and first obstructed. Both were first to enter the system after signal activation but no record was kept on how

long after the signals started flashing that this "first" car entered. In the comparison of phase II data to phase I data it was appropriate to define a "first" car in the same manner, that is without regard to the time interval between signal activation and the car's appearance. However, it was felt that additional information might be obtained if the phase II data were broken down into smaller groups that did consider this time interval.

The groupings were by subjective judgment of probable time affects. After several days of taking field data and studying the films, it was apparent that there were several possibilities for classifications that might be significantly different. These initial phase II groups and their comparisons are discussed below.

Group 1. A motorist who entered the system at approximately the same time that the signals were activated and who was the first to stop at the crossing.

Group 2. A motorist who entered the system 1-5 seconds after the signals were activated and who was the first to stop at the crossing.

Group 3. A motorist who entered the system more than 5 seconds after the signals were activated and who was the first to stop at the crossing.

Group 4. The second car to stop at the crossing although it was the first to enter the system after activation. The train had not reached the crossing when this vehicle stopped.

Group 5. The second car to stop at the crossing although it was the first to enter the system after activation. The train had reached the crossing when the vehicle stopped.

Group 6. The second car to enter the system after signal activation.[1]

Group 7. The third or greater vehicle to enter the system after signal activation.

Group 8. A vehicle which entered the system after the gates raised after the train passed and which did not have to stop.

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[1] This car was picked up with the camera after following the first through the traps; therefore, it was always several seconds after activation.

Group 9. A vehicle that was in an intermediate trap when the signal activated and did not stop.

Group 10. A vehicle that was in an intermediate trap when the signal activated and did stop.

Group 11. A free flow vehicle.

All of the above, except Groups 8, 9 and 10, are plotted in Figure 10. The numerical values of mean speeds at each trap can be read from Tables 10 and 11.

It should be pointed out that Groups 8, 9, and 10 were specialized cases not related to the primary purpose of the analysis and only a few cases were recorded. It was decided to include Groups 9 and 10 in the analysis however, since they are a real part of the total population that are affected by automatic gates. They are analyzed separately in a later section. Due to the limited sample of these cases, possible limitations of any inferences must be kept in mind.

Comparisons were made of all possible pairs of the phase II groups of approaching cars. There were not enough trucks in most groups to make meaningful comparisons. Therefore, trucks were included only in the free-flow group.

Groups 1 through 5 were all "first cars to enter the system after signal activation." Since Group 1 entered immediately after activation, it could be called the ideal "first" group. The other four were tested, pairwise, for significant difference from Group 1.

Group 2 was significantly different from Group 1 at the $\alpha = 0.10$ level in traps 4, 5 and 6, but there were no differences between Groups 1 and 3 and there were no differences between Groups 1 and 4 in any of the traps. Group 5 was significantly different at all traps (Table 10) and plotted more closely with "following" Groups 6 and 7, the second and third cars, respectively, to enter the system after signal activation (Figure 10). With the physical circumstances of a car ahead (already stopped or stopping) and a train across the road, it was decided that conditions were closer to those being associated with a "following car." Furthermore as shown by Table 11, Group 5 was not significantly different than either Groups 6 or 7 in any of the traps, supporting the

FIGURE 10. SPEED PROFILE OF ALL ORIGINAL CATEGORIES BEFORE GROUPINGS

INDEX FOR FIGURE

1. First into system just before signal activated and first to stop.
2. First into system 1-5 seconds after signal activated and first to stop.
3. First into system >5 seconds after signal activated and first to stop.
4. First into system after signal activated, second to stop but train not yet at crossing.
5. First into system after signal activated, second to stop but after train at crossing.
6. Second to enter the system after signal activation.
7. Third or greater vehicle to enter the system.

11. Free flow vehicles.

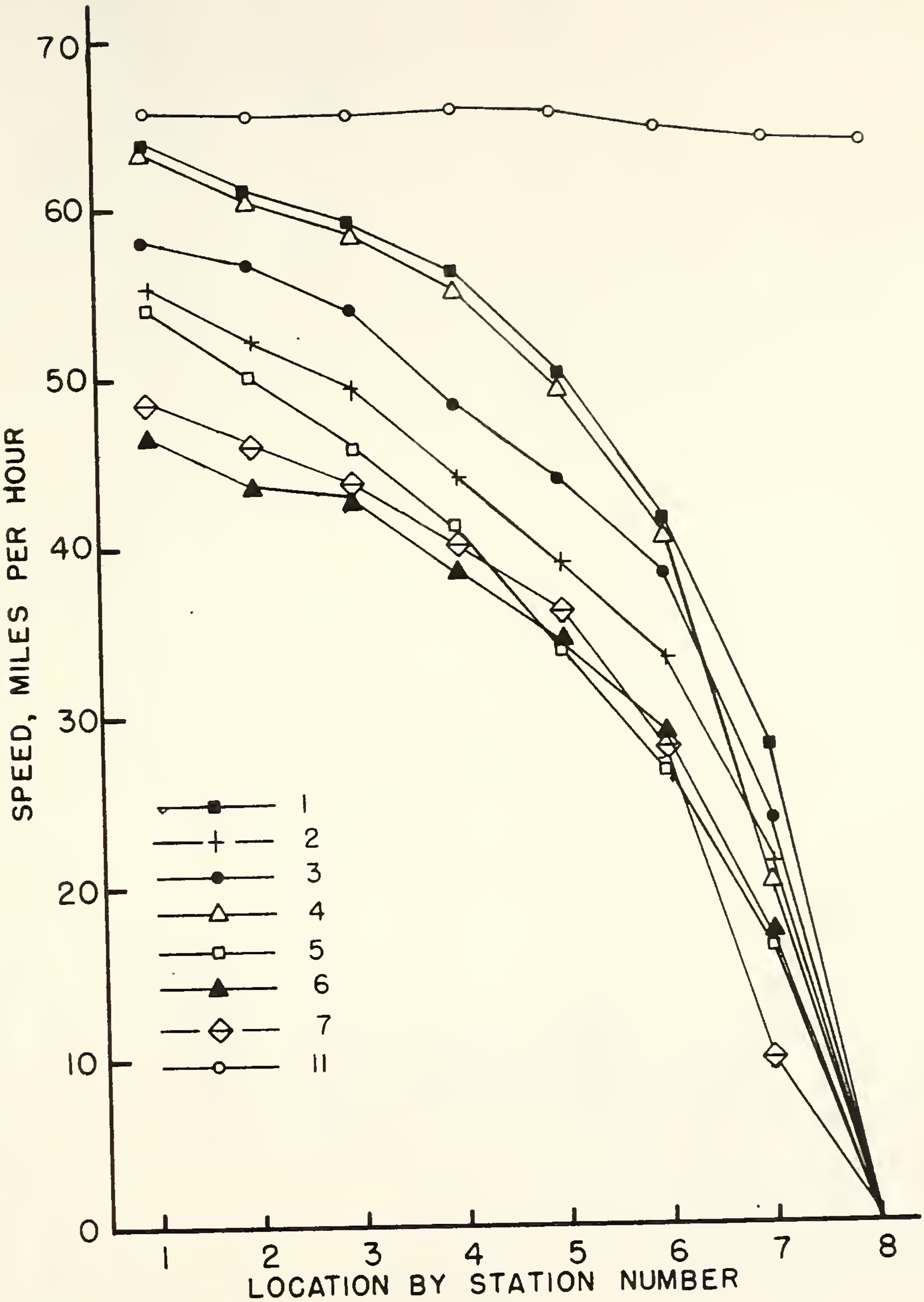
70
60
50
40
30
20
10
0
SPEED, MILES PER HOUR
1
2
3
4
5
6
7
11
1
2
3
4
5
6
7
8
LOCATION BY STATION NUMBER

FIGURE 10:

TABLE 10. SPEED LOCATION COMPARISONS FOR ORIGINAL GROUPINGS OF FIRST CARS INTO SYSTEM

			MEAN VALUES AT SPEED TRAP LOCATION							
			Trap #1	Trap #2	Trap #3	Trap #4	Trap #5	Trap #6	Trap #7	Trap #8
ORIGINAL TYPE-OF-FLOW GROUPS	GROUP NOS. n_1=6, n_2=5	1 2	63.9 55.4	61.1 52.1	59.1 49.5	56.2 44.1†	50.2 39.0†	41.6 33.3†	28.0 21.2	0 0
	GROUP NOS. n_1=6, n_2=6	1 3	63.9 58.1	61.1 56.9	59.1 53.9	56.2 48.5	50.2 43.9	41.6 38.5	28.0 24.0	0 0
	GROUP NOS. n_1=6, n_2=5	1 4	63.9 63.5	61.1 60.5	59.1 58.5	56.2 55.1	50.2 49.4	41.1 40.5	28.0 19.9	0 0
	GROUP NOS. n_1=6, n_2=6	1 5	63.9 54.5†	61.1 50.3†	59.1 47.7*	56.2 41.0*	50.2 33.9*	41.6 26.7**	28.0 16.2†	0 0

Note: All speeds in miles per hour

$H_0 : \mu_1 = \mu_2$ / $H_1 : \mu_1 \neq \mu_2$

† Difference significant at $0.12 > \alpha > 0.05$

* Difference significant at $\alpha = 0.05$

** Difference significant at $\alpha = 0.01$

TABLE 11. SPEED LOCATION COMPARISONS FOR ORIGINAL GROUPINGS OF SECOND AND GREATER CARS INTO SYSTEM

			MEAN VALUES AT SPEED TRAP LOCATION							
			Trap #1	Trap #2	Trap #3	Trap #4	Trap #5	Trap #6	Trap #7	Trap #8
ORIGINAL TYPE-OF-FLOW GROUPS	GROUP NOS.	6	46.7	43.8	42.8	38.5	34.0	28.4	16.6	0
	$n_1=5$, $n_2=6$	5	54.5	50.3	45.7	41.0	33.9	26.7	16.2	0
	GROUP NOS.	6	46.7	43.8	42.8	38.5	34.0	28.4	16.6	0
	$n_1=5$, $n_2=28$	7	48.7	46.2	43.6	40.3	35.9	28.2	9.9	0
	GROUP NOS.	7	48.7	46.2	43.6	40.3	35.9	28.2	9.9	0
	$n_1=28$, $n_2=6$	5	54.5	50.3	45.7	41.0	33.9	26.7	16.2	0

Note: All speeds in miles per hour

$H_0 : \mu_1 = \mu_2$ / $H_1 : \mu_2 \neq \mu_2$

† Difference significant at $0.10 > \alpha > 0.05$

* Difference significant at $\alpha = 0.05$

** Difference significant at $\alpha = 0.01$

decision to include it as a following car. No consideration was given to not including Group 2 with the first cars because this would have been inconsistent with the phase I data collection procedures. For future studies of this type, the time (after activation) of entry should be considered.

Because of the small sample sizes, no broad inferences can be drawn from comparisons of the speed distributions of the four first cars. However, it is interesting to note that Group 2 entered several miles per hour slower even though it entered Trap 1 as much as five seconds after signal activation. At 60 mph, this represents a travel distance as much as 440 feet and is an indication that the signals have an effect beyond the 1162-foot distance to Trap 1. This indication is further supported by the fact that all groups entering after signal activation entered slower than free-flow cars.

Groups 1 through 4 were subsequently analyzed together as one group of "first obstructed - after" as shown in Figure 11. Groups 5 through 7 were subsequently analyzed together as one group of "following - after" cars. A separate plot of these two larger groupings is shown in Figure 13 and a summary of the mean speeds can be seen in Table 12. The difference in speeds between "first" and "following" cars is significant in all traps.

Integration of the Before Data

The speed data taken before the gates had been installed, the "before" data, were recoded to conform to the coding of the "after" data and incorporated with it into one data set. Thus, comparisons within the before subset could be reproduced as well as any others that might be of interest.

The primary methodology for comparison involved selected comparisons of speeds and decelerations of vehicles approaching the crossing. Speeds, as stated earlier, were determined at each trap for all vehicles by the formula:

$$\text{mph} = \frac{900}{\text{number of frames}}$$

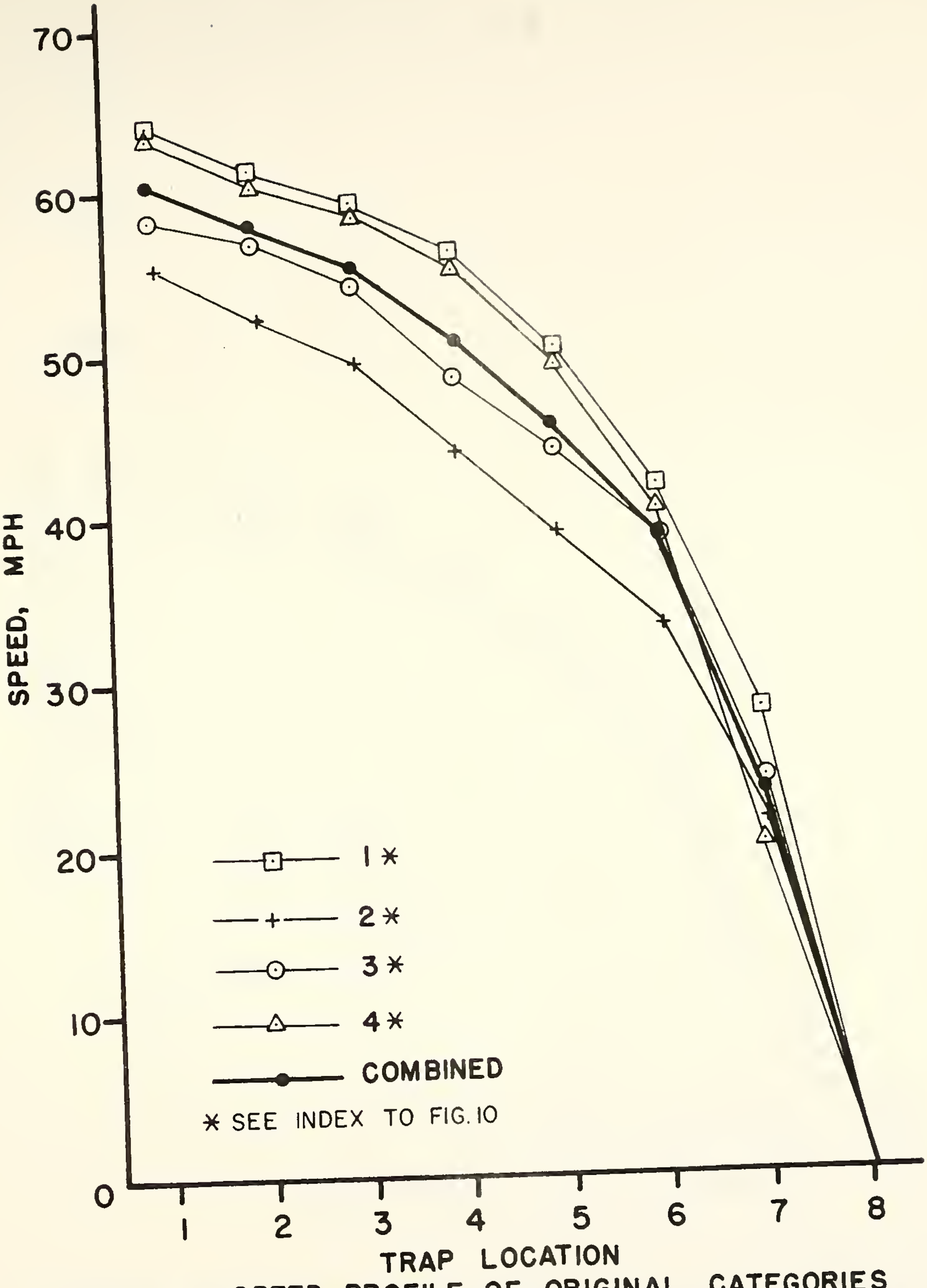

FIGURE 11: SPEED PROFILE OF ORIGINAL CATEGORIES GROUPED TO FORM AFTER "FIRST OBSTRUCTED"

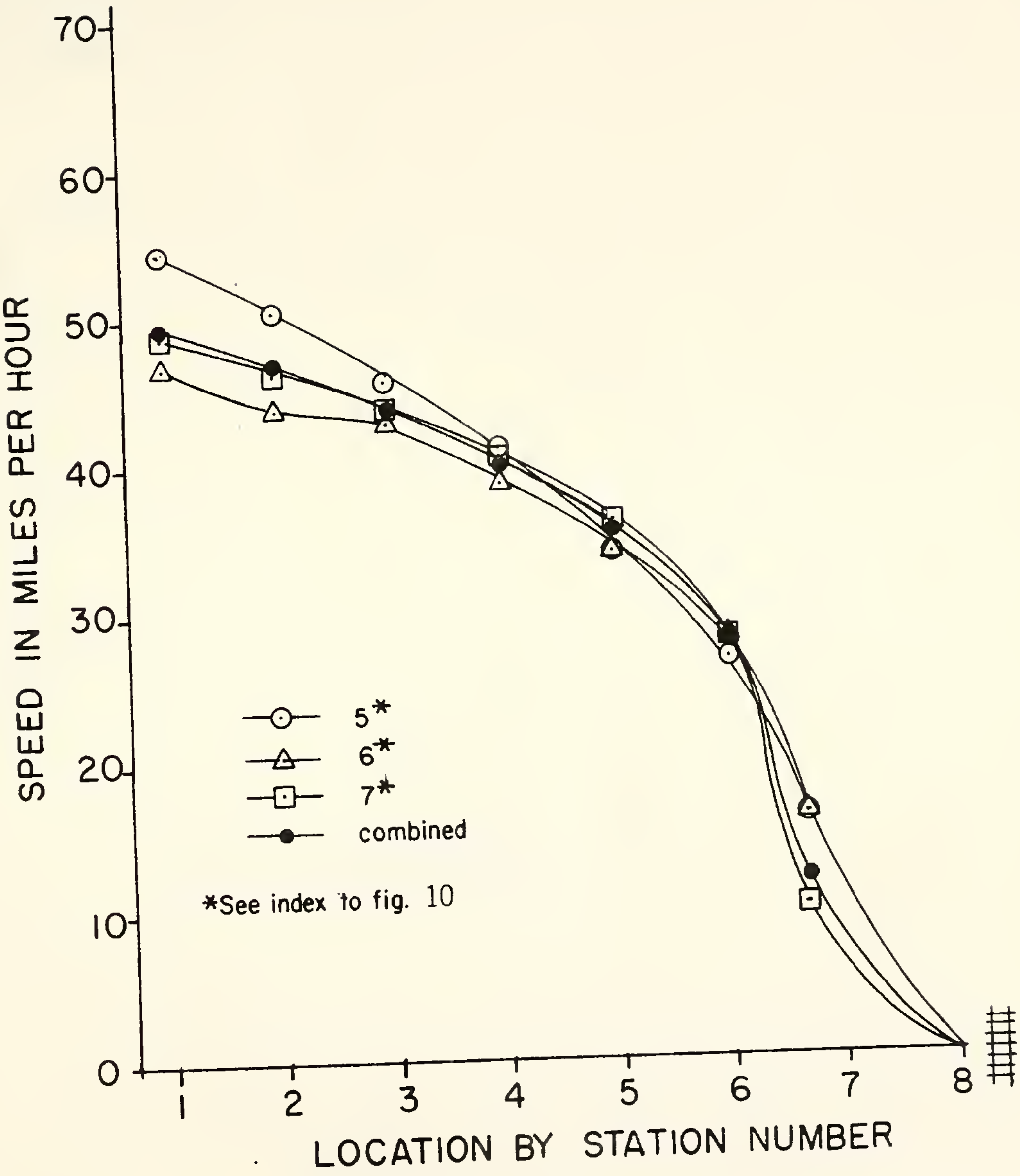

FIGURE 12: SPEED PROFILES OF ORIGINAL CATEGORIES GROUPED TO FORM "FOLLOWING-AFTER "GROUPS"

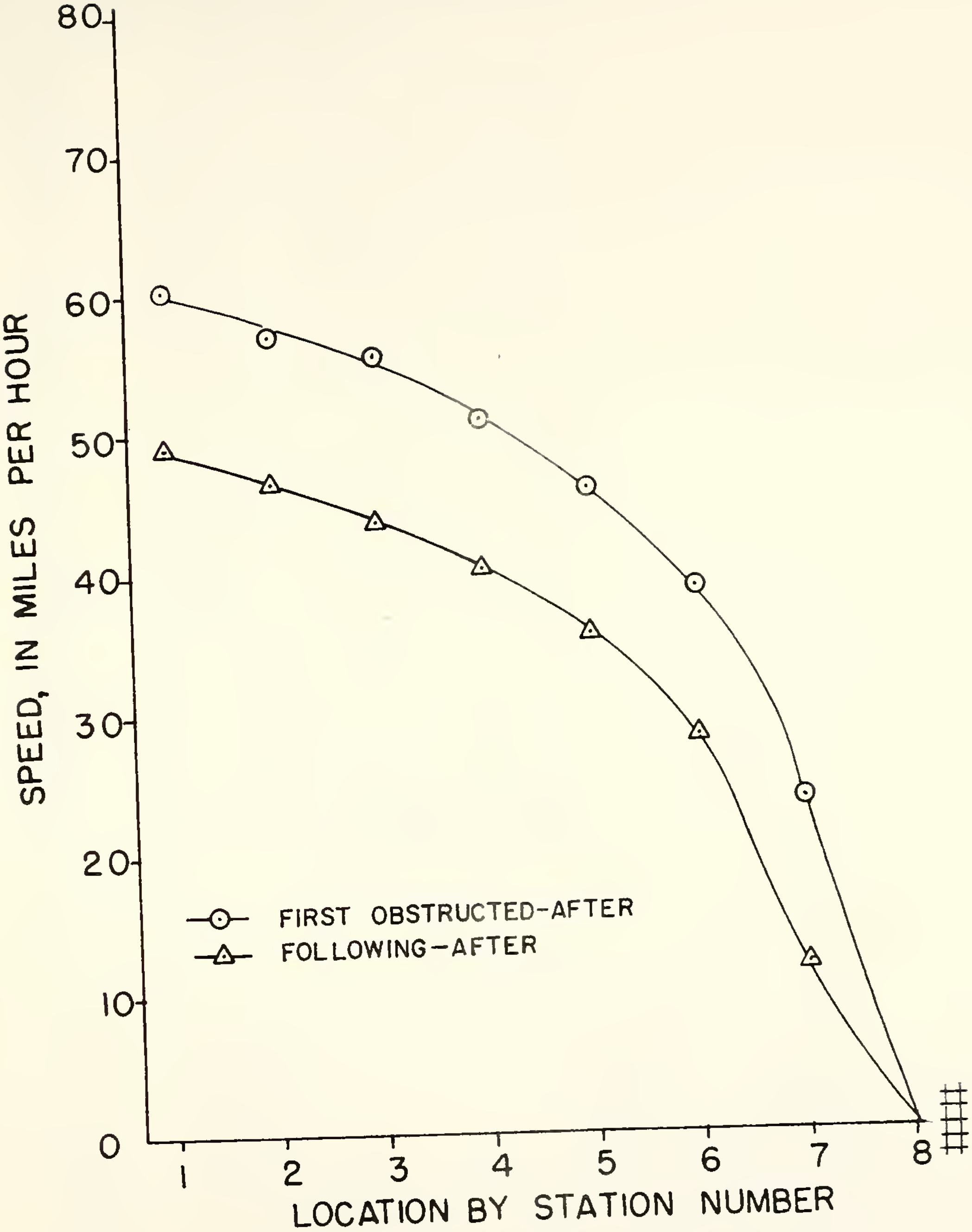

FIGURE 13: SPEED PROFILES OF FINAL COMBINED GROUPINGS OF "FIRST OBSTRUCTED-AFTER" AND "FOLLOWING-AFTER" VEHICLES

TABLE 12. SPEED LOCATION COMPARISONS FOR COMBINED GROUPINGS OF "FIRST OBSTRUCTED - AFTER" AND "FOLLOWING - AFTER"

VEHICLE CLASSIFICATION PAIRS TESTED FOR SIGNIFICANT DIFFERENCE				MEAN VALUES AT SPEED TRAP LOCATION							
				Trap #1	Trap #2	Trap #3	Trap #4	Trap #5	Trap #6	Trap #7	Trap #8
1. FIRST OBSTRUCTED - AFTER, n_1=22	a	SPEED	1	60.3	57.8	55.3	51.1	45.8	38.6	23.5	0
			2	49.3**	46.5**	43.8**	40.1**	35.4**	28.0**	11.7**	0
2. FOLLOWING AFTER, n_2=39	b	DECEL-ERATION	1		2.04	1.82	3.18	3.73	4.32	5.73	4.86
			2		1.77	1.62	2.23*	2.56**	3.15*	4.15*	1.90

Note: Speed in miles per hour

Deceleration in ft/sec/sec

$H_0 : \mu_1 = \mu_2 \ / \ H_1 : \mu_1 \neq \mu_2$

† Difference significant at $0.10 < \alpha < 0.05$

* Difference significant at $\alpha = 0.05$

** Difference significant at $\alpha = 0.01$

Deceleration rates were determined between each trap for all vehicles by the formula:

$$V_f = V_0 - \sqrt{2dl}$$

where: V_f = final velocity in feet per sec.

V_0 = initial velocity in feet per sec.

d = deceleration rate in feet per sec. per sec.

l = distance in feet

Substituting the necessary conversion factors and a value for l of 155 feet the formula reduces to:

$$d = \frac{V_0^2 - V_f^2}{144.19}$$

where: d = deceleration rate in feet per sec. per sec.

V_0 = initial velocity in miles per hour

V_f = final velocity in miles per hour

Categories. Previously discussed were the categories into which Butcher had grouped the before data; namely, free-flow, first unobstructed, first obstructed and following cars (29). By definition, a first unobstructed car was one that entered and approached the system, passing through while the signals were flashing but while the train was far enough away to not put the driver in any real danger. With the gate system, the gates started down when the signals were activated. Thus, a first car entering Trap 1, 1162 feet from the track had little or no chance to beat the gate. The gates were down approximately ten seconds after activation of the system. Assuming that they would be low enough to be hit by a car roof in eight seconds, a car would have to travel approximately 99 mph (145 ft/sec) to "beat the gate." Thus, the assumption of the after study that first drivers entering the speed trap system after activation were obstructed by the gate across the road appears to be a reasonable one.

Another factor was the addition of a Marquardt speed predictor. The estimated train speed at the crossing ranged from 20 to 60 mph resulting, under the old system, that signals started flashing an estimated 60 to 90 seconds before the train was at the crossing. Thus

a first car into the old system had sufficient time to approach and cross ahead of a train in the slower train speed range. The Marquardt predictor gave a uniform 20 to 25 second warning. It is reasonable to assume that only the most aggressive drivers entering trap 1 at the time of signal activation would not perceive the train as being close enough to be a hazard. Thus, even if there were no gates, the Marquardt speed predictor itself would essentially have eliminated the "first unobstructed" category of phase I.

It was concluded from the above considerations that it would be appropriate to label the phase II, "first cars" entering the system as "first obstructed - after" and to make statistical comparisons with the before category of first obstructed vehicles. It is important to note that automatic gates essentially eliminated driver decision, except for those very close to the crossing, relative to proceeding across the crossing after the flashing lights had been activated. This is where a driver may make the bad decision that no hazard exists because of the approaching train when, in fact, it does.

Summary. The after data were composed of only two categories that could be compared to the before data; namely "first obstructed - after" and "following" cars. The case of the "first obstructed - after" was defined differently than the before case, that is, in the before case the train itself was the obstruction and in the after case the gate arms were the obstruction.

Comparison of the Before and After Analysis

The Crossing Protection - Before

The crossing was protected by two sets of flashing light signals and reflectorized crossbucks. There was an additional set of flashing lights aimed down each approach of County Road 100 S. Times of signal activation before the train reached the crossing varied greatly with times up to 90 seconds observed for some particularly slow moving trains. The signals were an "older" type with 8 inch diameter lens.

Standard advance warning signs were placed in pairs, one on each side of the road of each approach, at a distance of 1000 feet from the tracks. As a temporary countermeasure to public pressure to improve protection at the crossing, one yellow flasher of the construction barricade type had been attached to each advance warning sign. They were small and dim and flashed continuously. These remained in place throughout the collection of phase I data. There was no reasonable way to measure their effect.

Standard pavement markings were painted across both lanes of each approach. All signs, signals, and markings were well maintained and in good order.

The Crossing Protection - After

The upgraded Goldsmith protection system consisted primarily of automatic gates with full width gate-arms. The gates across the southbound lanes were designed and placed to block three lanes, that is, the two existing lanes plus a future left-turn lane to the county road planned by the State Highway Commission. These were supplemented by several pairs of flashing lights. On the southbound approach (because of the greater pavement width) there was one pair on each side of the roadway as well as one pair over each lane on a tubular, cantilever structure. On the northbound approach there were only two pair, one over each roadway. In addition there was one pair of flashing lights aimed toward each approach of C. R. 100 S. All flashers are larger (12-inch lenses) and brighter than the ones that had been in place originally.

The gate arms have the standard, lantern-type red lights on each arm. In addition, six strobe lights were installed on each arm. The strobe lights have red lenses aimed toward each approach and are activated concurrently with the standard flashers. Each strobe light flashes independently of all others.

New reflectorized advance warning signs were placed on each approach, in place of the original ones. No yellow flasher was used with the new signs. Standard pavement markings were in place as before.

This active system, gates, flashers, arm lanterns and strobes, are all activated by a Marquardt speed predictor. The Marquardt system "calculates" the train's speed and activates the signals such that all trains are 25 seconds away from the crossing regardless of speed. A schematic view of the crossing has been shown previously in Figure 7 and a series of photographic views is shown in Figures 14 through 17.

After the phase I (before) data were recoded it was analyzed with the after data as a complete set. All the raw before data were rerun because the Purdue Computer center had changed its primary statistical package from the BMD series to SPSS (Statistical Package for the Social Sciences) programs in the interim between the two phases.

Preliminary Considerations

The first concern was to determine insofar as possible, if the after data were reasonably consistent with the before data. It is reasonable to assume that the free-flow data should be the most stable, before and after, because of the relatively large number of observations as well as the fact that the free-flow entry speeds (trap #1) were not expected to be affected by the crossing improvement to any significant degree because of the distance from the crossing (>1000 feet).

TABLE 13. NUMBER OF OBSERVATIONS IN EACH VEHICLE CLASSIFICATION

Classification	Northbound		Southbound	
	Before	After	Before	After
Free Flow Trucks	79	22	46	26
Free Flow Cars	143	93	144	59
First Unobstructed Cars	15	--*	15	--*
First Obstructed Cars	10	9	10	13
Following Cars	25	17	33	22
Totals	272	141	248	120

* No comparative group in after phase.

(A) AFTER IMPROVEMENT

(B) BEFORE IMPROVEMENT (29)

FIGURE 14. THE GOLDSMITH GRADE CROSSING AS VIEWED FROM THE NORTHBOUND LANES OF U. S. 31 BEFORE AND AFTER PROTECTION IMPROVEMENT

(A) AFTER IMPROVEMENT

(B) BEFORE IMPROVEMENT (29)

FIGURE 15. THE GOLDSMITH GRADE CROSSING AS VIEWED FROM THE SOUTHBOUND LANES OF U. S. 31 BEFORE AND AFTER PROTECTION IMPROVEMENT

FIGURE 16. TWO VIEWS OF THE GOLDSMITH GRADE CROSSING AS VIEWED FROM THE SOUTHBOUND LANES OF U. S. 31 EMPHASIZING BACKGROUND OF TREES

(A) AFTER IMPROVEMENT

(B) BEFORE IMPROVEMENT (29)

FIGURE 17. THE GOLDSMITH GRADE CROSSING AS VIEWED FROM 100S LOOKING WEST PARALLEL TO TRACKS

The mean entry speeds and tests of differences between mean entry speeds for various categories of southbound and northbound cars for both phase I and phase II are shown in Table 14 and Table 15 respectively. The entry speeds, standard deviations, and statistical test results of the before data analysis are as reported in the Interim Report (29, p. 81).

The mean entry speeds of all categories of free-flow cars appear to be of the same magnitude and, with one exception, have the same standard deviation. That exception is the relatively low standard deviation of southbound, free-flow trucks. An F-test of the variance showed that the difference is significant. Since all other categories have no significant differences between before and after comparisons of variance, it is unlikely that this difference is due to differences in before and after data collection techniques. The histogram delineating the southbound, free-flow truck speed distribution, Figure 18, indicates the possibility of bias in the after group toward the 45-50 mph group. The distribution of the before data is obviously more normal and less suspect of bias; however, neither the data nor observation during the summer gave any indication of what the cause might be. It was noted throughout the summer, however, that many trucks braked and slowed noticeably, apparently for crossing roughness. One possibility is that the after group of truck drivers were more aware of the crossing ahead because of the gate arms and were entering slower due to anticipated roughness ahead.

One result from the phase I data was that the mean entry speeds of northbound and southbound free-flow cars were significantly different. That analysis also found that the mean entry speeds of northbound and southbound free-flow trucks were significantly different. A summary of the statistical tests from that analysis is shown in Table 14. This result was explained by Butcher as follows (29):

> This phenomenon may possibly be attributed to a combination of two situations peculiar to the northbound approach. First, all northbound vehicles had just passed through the signal controlled intersection of U. S. 31 and S. R. 28 approximately one mile south of the railroad crossing. The travel speeds of these

TABLE 14. TESTS ON DIFFERENCES BETWEEN MEAN ENTRY SPEEDS FOR ALL FREE-FLOW VEHICLES BEFORE UPGRADING PROTECTION

VEHICLE CLASSIFICATION	N	MEAN ENTRY SPEED	STD DEV S	$H_0: \sigma_1^2 = \sigma_2^2 / H_1: \sigma_1^2 \neq \sigma_2^2$			$H_0: \mu_1 = \mu_2 / H_1: \mu_1 \neq \mu_2$		
				F-VALUE	2-TAIL PROB	RESULT	t-VALUE	2-TAIL PROB	RESULT
1. S.B. FREE FLOW CARS 2. N.B. FREE FLOW CARS	143 144	68.3 65.6	6.4 6.9	1.15	0.394	DO NOT REJECT	3.41	0.001	REJECT**
1. S.B. FREE FLOW TRUCKS 2. N.B. FREE FLOW TRUCKS	46 79	58.3 53.4	6.7 7.1	1.12	0.685	DO NOT REJECT	3.82	0.000	REJECT**
1. S.B. FREE FLOW CARS 2. N.B. FREE FLOW TRUCKS	143 46	68.3 58.3	6.3 6.6	1.07	0.753	DO NOT REJECT	9.18	0.000	REJECT**
1. N.B. FREE FLOW CARS 2. N.B. FREE FLOW TRUCKS	144 79	65.6 53.4	6.9 7.1	1.04	0.842	DO NOT REJECT	12.48	0.000	REJECT**

Note: Similar to Butcher (Ref. 29). Data reformatted and tests run by computer with SPSS package causing slight differences in the values but not in the results.

* Result significant at $\alpha = .05$

** Result significant at $\alpha = .01$

TABLE 15. TESTS ON DIFFERENCES BETWEEN MEAN ENTRY SPEEDS FOR ALL FREE-FLOW VEHICLES AFTER UPGRADING PROTECTION

VEHICLE CLASSIFICATION	N	MEAN ENTRY SPEED	STD DEV S	$H_0: \sigma_1^2 = \sigma_2^2 / H_1: \sigma_1^2 \neq \sigma_2^2$			$H_0: \mu_1 = \mu_2 / H_1: \mu_1 \neq \mu_2$		
				F-VALUE	2-TAIL PROB	RESULT	t-VALUE	2-TAIL PROB	RESULT
1. S.B. FREE FLOW CARS 2. N.B. FREE FLOW CARS	59 93	66.3 65.4	7.6 7.2	1.09	0.698	DO NOT REJECT	0.74	0.461	DO NOT REJECT
1. S.B. FREE FLOW TRUCKS 2. N.B. FREE FLOW TRUCKS	26 22	52.4 50.6	4.1 6.6	2.53	0.028	REJECT*	1.10	0.279	DO NOT REJECT†
1. S.B. FREE FLOW CARS 2. S.B. FREE FLOW TRUCKS	50 26	66.3 52.4	7.6 4.1	3.37	0.001	REJECT**	10.88	0.000	REJECT** †
1. N.B. FREE FLOW CARS 2. N.B. FREE FLOW TRUCKS	93 22	65.4 50.6	7.2 6.6	1.22	0.625	DO NOT REJECT	8.73	0.000	REJECT**

* Result significant at $\alpha = .05$

** Result significant at $\alpha = .01$

† Approximate t-test using separate variances

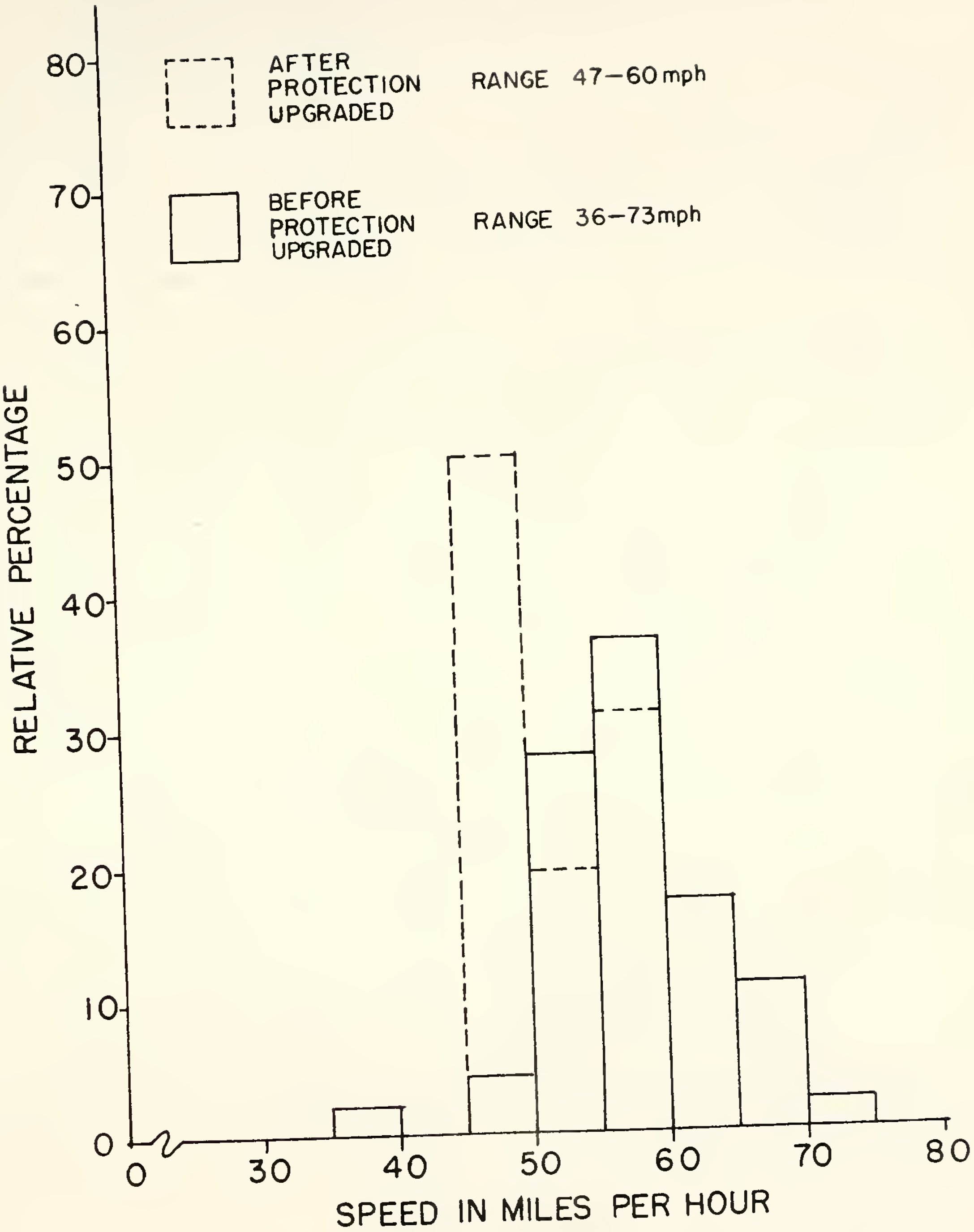

FIGURE 18: SPEED DISTRIBUTION HISTOGRAM OF BEFORE AND AFTER DATA FOR ENTRY SPEED OF FREE-FLOW SOUTHBOUND TRUCKS

vehicles, especially trucks, may not have leveled off before reaching the crossing. Second, sight distance to the east is restricted for northbound vehicles, as discussed earlier, so a bit more caution may have been exercised by these drivers.

A similar analysis was made with the phase II data and the results were different than those of phase I. Although analysis of the after data showed that the values of mean entry speeds of both southbound free-flow cars and trucks were slightly higher than their respective northbound values, the differences were not significant in either case, as can be seen in Tables 15 and 16.

There are several possible reasons for the above differences. First, the writer tends to doubt that the signal per se, one mile to the south, has much affect. This writer is inclined to attribute the difference to driver expectancy. A northbound driver in the two or three miles prior to the crossing passes not only the traffic light but several houses, roadside businesses and a major at-grade intersection. Just prior to the crossing there is a County Road. The southbound driver has had a level, straight, wide-open, "freeway-type" facility for at least 10 miles. A driver is easily lulled into what may be called a "freeway feeling" and a false sense of security, and does not expect cross obstructions such as a railroad crossing at grade.

The differences in sight distance could be a factor. The southbound driver has no sight restriction to either side along the tracks, whereas the northbound driver has a restricted sight distance to the west. Also, the old signals, being close to the ground, were not visible against the horizon before protection improvement.

Under phase II conditions, the gates in the "up" position are visible against the horizon. One is now more aware "something" is ahead even if not initially recognizing it as a grade crossing.

Method of Comparison

The primary method of analyzing data within the phase I subset had been by comparing entry speeds, approach speed profiles and deceleration rates. Some refinements were made when analyzing the

TABLE 16. SPEED LOCATION AND DECELERATION NORTHBOUND VS SOUTHBOUND TRUCKS BEFORE AND AFTER

VEHICLE CLASSIFICATION PAIRS TESTED FOR SIGNIFICANT DIFFERENCE			MEAN VALUES AT SPEED TRAP LOCATIONS							
			Trap #1	Trap #2	Trap #3	Trap #4	Trap #5	Trap #6	Trap #7	Trap #8
NORTHBOUND VS SOUTHBOUND TRUCK (AFTER)	SPEED	NB	50.6	51.3	52.5	52.5	53.2	53.0	52.0	51.8
		SB	52.4	52.2	52.0	52.1	51.3	51.2	50.7	50.1
	DECEL-ERATION	NB		-.55	-.86	0.0	.50	0.14	0.63	-.05
		SB		0.11*	0.19**	-.07	0.46**	-.04	0.31	0.15
NORTHBOUND VS SOUTHBOUND TRUCK (BEFORE)	SPEED	NB	53.4	53.5	54.0	54.1	54.1	53.7	52.6	51.5
		SB	58.3**	58.1**	57.6*	57.8*	56.7*	56.1†	55.7*	55.3*
	DECEL-ERATION	NB		-.06	-.41	-.10	-.15	0.25	0.73	0.54
		SB		0.19*	0.32**	-.21	0.87**	0.51†	0.26	0.32

Note: All speeds in miles per hour

$H_0 : \mu_1 = \mu_2 \ / \ H_1 : \mu_1 \neq \mu_2$

† Difference significant at $0.10 > \alpha > 0.05$

* Difference significant at $\alpha = 0.05$

** Difference significant at $\alpha = 0.001$

phase II data. First the phase I summary data reported speed at each trap and speed at each trap as a percentage of entry speed. No real use was made of the percentages, however, nor was any value apparent in analyzing before and after differences. Therefore, these are not included herein. In their place, deceleration rates were calculated and recorded along with all appropriate speed data. Thus, for all "mean values at speed-trap locations" reported, all corresponding between trap mean decelerations are included.

The second refinement was that a t-test of the means was performed on a trap by trap basis. That is, the only tests that were run on phase I data were to determine significance between entry speeds; but on the phase II data a test was performed for significant differences in mean speeds at each of the eight traps as well as each of the seven deceleration zones between traps.

Mean deceleration rates are of such a low magnitude that they are relatively meaningless parameters. Their analysis in a later section discusses this point. However, showing the deceleration rates in the tables does make trends in the speed profile more clear.

Free-Flow Speed Profile Comparisons

The primary purpose of this study was concerned with determining the effect of activation of the new signal system on drivers. This effect will be discussed in the next section. A brief comparison of the free-flow data and its analysis follows.

The results of the analysis of free-flow vehicles are presented in Table 17 and Figures 19 and 20. Two points are obvious from the plots of the approach speeds of all classes of vehicles. First, there is a decrease in after speed, relative to before speed, at all traps along each profile except that the entry (Trap 1) speed for northbound cars was about the same. Secondly, before and after speed profiles for their respective groups are essentially parallel. These two factors indicate that motorist responses to both the old and new system were similar but at slightly reduced speed throughout their approach for the after condition. Comparing northbound and southbound

TABLE 17. SPEED LOCATION AND DECELERATION - BEFORE AND AFTER COMPARISONS OF FREE-FLOW CARS AND TRUCKS

VEHICLE CLASSIFICATION PAIRS TESTED FOR SIGNIFICANT DIFFERENCE		MEAN VALUES AT SPEED TRAP LOCATIONS								TABULAR t-VALUES FOR 1 TAIL TEST	
		Trap #1	Trap #2	Trap #3	Trap #4	Trap #5	Trap #6	Trap #7	Trap #8	α	VALUE
SOUTHBOUND FREE-FLOW CARS, $n_1=144$, $n_2=59$	a SPEED 1	68.3	68.2	68.1	68.5	67.6	67.1	66.9	66.3	α=.10	1.282
	SPEED 2	66.3*	66.2*	66.4†	66.6*	65.6*	65.5*	65.4*	65.5	α=.05	1.645
	t-VALUE	-1.95	-1.87	-1.56	-1.82	-1.76	-1.47	-1.30	-0.72	α=.01	2.326
	b DECELERATION 1		0.13	0.13	-0.44	0.83	0.42	0.20	0.48		
	DECELERATION 2		0.07	-0.17	-0.14	0.85	0.17	0.07	-0.10		
	t-VALUE		-0.30	-1.56	1.61†	0.09	-0.94	-0.56	-2.82		
NORTHBOUND FREE-FLOW CARS, $n_1=143$, $n_2=93$	a SPEED 1	65.7	65.7	66.2	66.2	66.1	65.4	63.8	62.8	α=.10	1.282
	SPEED 2	65.4	64.7	64.9*	65.2	65.3	64.1	62.8	62.4	α=.05	1.645
	t-VALUE	-0.28	-1.19	-1.35	-1.05	-0.77	-1.26	-0.99	-0.37	α=.01	2.326
	b DECELERATION 1		-0.06	-0.4	0.0	0.1	0.6	1.3	0.8		
	DECELERATION 2		0.72	-0.3	-0.2	-0.2	1.0	1.1	0.2		
	t-VALUE		3.91	0.63	-1.28	-1.59	2.11	-0.65	-2.93		
SOUTHBOUND FREE-FLOW TRUCKS, $n_1=47$, $n_2=26$	a SPEED 1	58.3	58.1	57.6	57.8	56.7	56.1	55.7	55.3	α=.10	1.296
	SPEED 2	52.4**	52.3**	52.0**	52.1**	51.3**	51.2**	50.7**	50.1**	α=.05	1.671
	t-VALUE	-4.09	-3.88	-3.65	-3.63	-3.29	-2.82	-2.56	-2.39	α=.01	2.390
	b DECELERATION 1		0.19	0.32	-0.21	0.87	0.51	0.26	0.32		
	DECELERATION 2		0.12	0.19	-0.07	0.46	-0.04	0.31	0.15		
	t-VALUE		-0.43	-0.72	-0.67	-1.70	-2.19	0.18	-0.64		
NORTHBOUND FREE-FLOW TRUCKS, $n_1=79$, $n_2=22$	a SPEED 1	53.4	53.5	54.0	54.1	54.1	53.7	52.6	51.4	α=.10	1.282
	SPEED 2	50.6*	51.3†	52.5	52.5	53.2	53.0	52.0	51.8	α=.05	1.645
	t-VALUE	-1.67	-1.31	-0.90	-0.96	-0.52	-0.39	-0.28	+0.11	α=.01	2.326
	b DECELERATION 1		-0.06	-0.41	-0.10	-0.05	0.25	0.73	0.54		
	DECELERATION 2		-0.54	-0.86	0.0	-0.50	0.14	0.64	0.05		
	t-VALUE		-1.84	-2.37	0.47	-2.45	-0.50	-0.31	-1.52		

TABLE 17. CONTINUED

Notes:

1. Before system improvement
2. After system improvement

$H_0: \mu_1 = \mu_2$ / $H_1: \mu_1 < \mu_2$

† Difference significant at $0.10 > \alpha > 0.05$

* Difference significant at $\alpha = 0.05$

** Difference significant at $\alpha = 0.001$

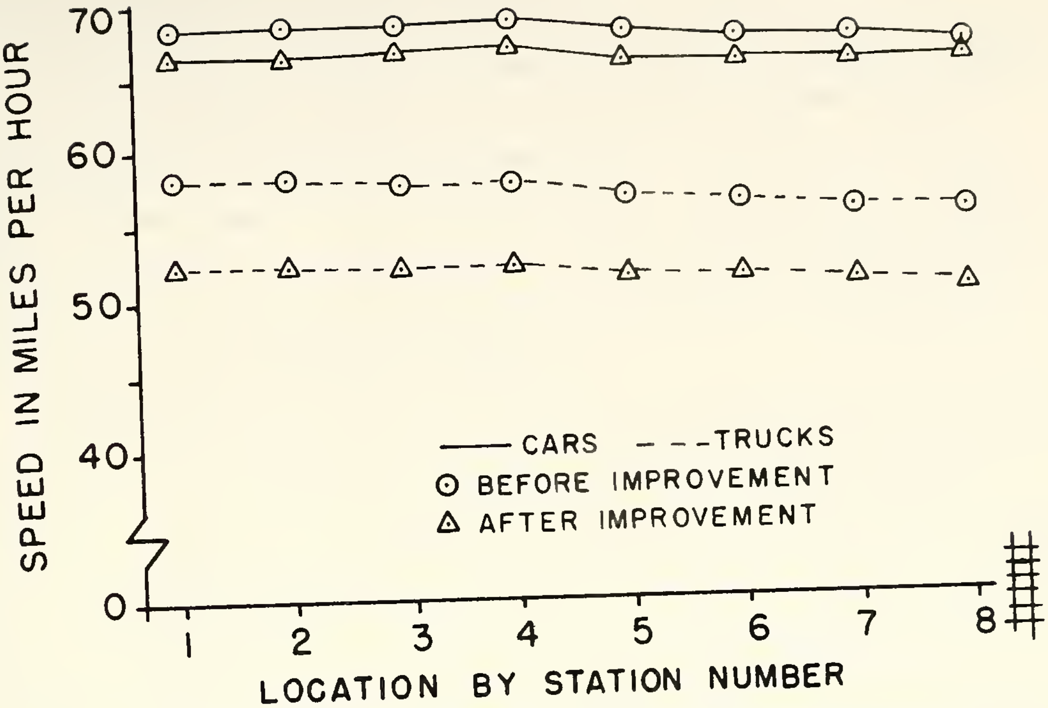

FIGURE 19: SPEED LOCATION GRAPH FOR SOUTHBOUND FREE-FLOW CARS

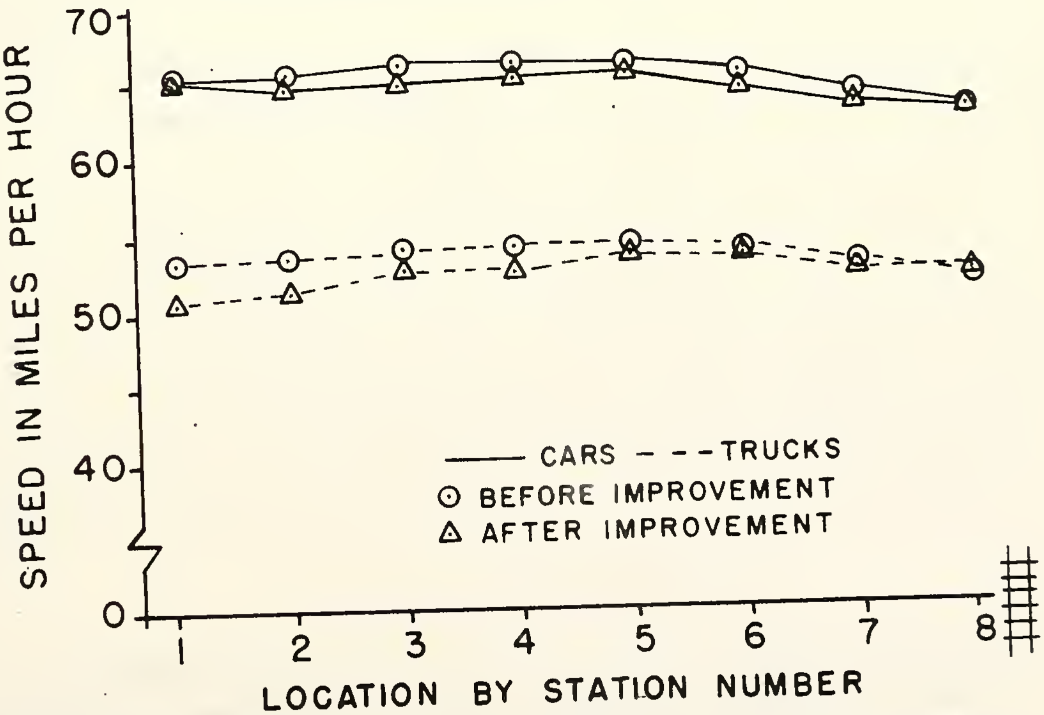

FIGURE 20: SPEED LOCATION GRAPH FOR NORTHBOUND FREE-FLOW CARS

speed profiles showed slightly higher speeds in all categories of southbound vehicles both before and after.

On the northbound approach, comparing before and after, the entry speeds of cars were the same but the after profile showed initial deceleration at a greater rate between Trap 1 and Trap 2. Trucks, after, entered slower on both approaches as did cars, after, on the southbound approach. The implication is that the average driver was more aware of the crossing during phase II, even at the entry point, particularly on the southbound approach.

Another observation that can be made, particularly from Figures 19 and 20, is the point that the motorist begins decelerating for the crossing. On the southbound approach, cars and trucks, before and after, all start their deceleration, albeit slight, at Trap 4 (Figure 19) or about 700 feet from the crossing. The implication is that this point is independent of both vehicle and protection type. On the northbound approach (excluding the initial deceleration of after cars at the entry point) cars and trucks, before and after, all start their deceleration at Trap 5 or 6 or approximately 400 to 500 feet from the crossing.

Sanders concluded that (3, p. 508): "The resulting (speed) profiles showed that the crossing does not influence traffic behavior beyond 500 feet." This study does not support this conclusion. Entry speeds indicate some effect at more than 1000 feet and on the southbound approach, there is noticeable deceleration at 700 feet.

The grade crossings of Sanders' study were in urban or suburban environments. The northbound approach at the Goldsmith grade crossing could be categorized as being suburban in nature; whereas the southbound approach is strictly rural. The implication is that on high-speed, rural grade crossing approaches drivers take action sooner.

Free-Flow Deceleration Rates

The mean deceleration rates, particularly for the free-flow categories, were used only as an aid in analyzing trends in the speed profile. However, one driver characteristic can be noted. Drivers

did not decelerate at a constant rate from point of initial action to desired slower speed at or near the crossing. A driver was more likely to decelerate early, maintain lower speed or accelerate again in some cases, then decelerate again closer to the crossing. This pattern is evident from the nonuniformity of the speed profiles as can be seen in Figures 19 and 20 and the variations in the actual rates that can be noted in Table 17. This characteristic is consistent with findings by Sanders on several suburban crossings (3, p. 7-4):

> ...the population tends to brake for short periods during the approach such that the measured maximum deceleration resulted in the major proportion of the total speed decrease rather than making a smaller braking effort for a longer period of time

In other words, a driver's deceleration rate was variable during his approach to a grade crossing. However, Sanders found that the point of maximum deceleration was generally about 45 feet from the crossing, indicating that drivers waited as long as possible before braking, the data from the Goldsmith crossing study indicate maximum braking prior to Trap 7, greater than 200 feet from the crossing. This could be another significant difference between rural and suburban (or urban) grade crossings. It also indicates that drivers on a high speed rural approach will react early if alerted early.

Free-Flow Speed Distributions

In addition to analyzing mean speeds and mean speed profiles, the distribution of speeds was examined. First, this was done in order to determine if the pace speed had changed from phase I, and to make comparisons of the before and after data set of above-pace-speed vehicles. Appendix A contains a series of speed distribution charts A1 through A12. These relative and cumulative speed distribution curves are for selected distributions at Trap 1 (entry speed), Trap 5 (mid-point) and Trap 8.

The frequency distribution curve, Figure A2, shows that the phase I pace speed is 62.5 to 72.5 mph. The phase II pace speed is 61.5 to 71.5 mph. From a practical standpoint, one could say that the

before and after pace speeds were both 62 to 72 mph. Within the limits of accuracy of the data and the accuracy of plotting Figure A2 it was concluded that the pace speed did not change significantly.

On the other hand, the distribution of speeds has shifted toward the "slow side," i.e., a higher percentage of vehicles is traveling at lower speeds. This fact is more easily seen in the before and after southbound cumulative speed curves, Figure A3. It can be seen in the frequency distribution curve of entry speeds, Figure A3, that 18% of the vehicles were traveling above the pace speed after system improvement whereas 28% were traveling above pace speed before system improvement. Likewise, whereas the range of entry speeds before was 45 to 90 mph, the range of speeds after was 40 to 80 mph. Also, from the cumulative speed curve, Figure A3, the 85th percentile speed was lowered from 74 to 71 mph at the entry trap.

Although data were not plotted for all speed traps, the data showed similar results at all traps, both southbound and northbound. An "average speed distribution" was calculated by taking the mean of all eight traps for a given speed group. The cumulative speed distribution curves for both southbound and northbound approaches, based on these averages are shown in Figures 21 and 22. It can be concluded that the above analysis of the speed data, corresponds with the statistical analysis of the mean values at speed trap locations, i.e., shift toward lower approach speeds because of the gate arms.

Above Pace, Free-Flow Speed Comparisons

The calculated pace speed was 62.5 - 72.5 mph before and 61.5 to 71.5 after, as determined from the frequency distribution curve of Figure A2. It was decided that 62 - 72 mph would be close enough for both before and after southbound data as well as before and after northbound data. The cumulative speed curve of entering northbound and southbound free-flow cars, Figures 21 and 22, show that this is not an unreasonable assumption.

It should be noted that in the Interim Report (29), Butcher reported different pace speeds for northbound and southbound vehicles.

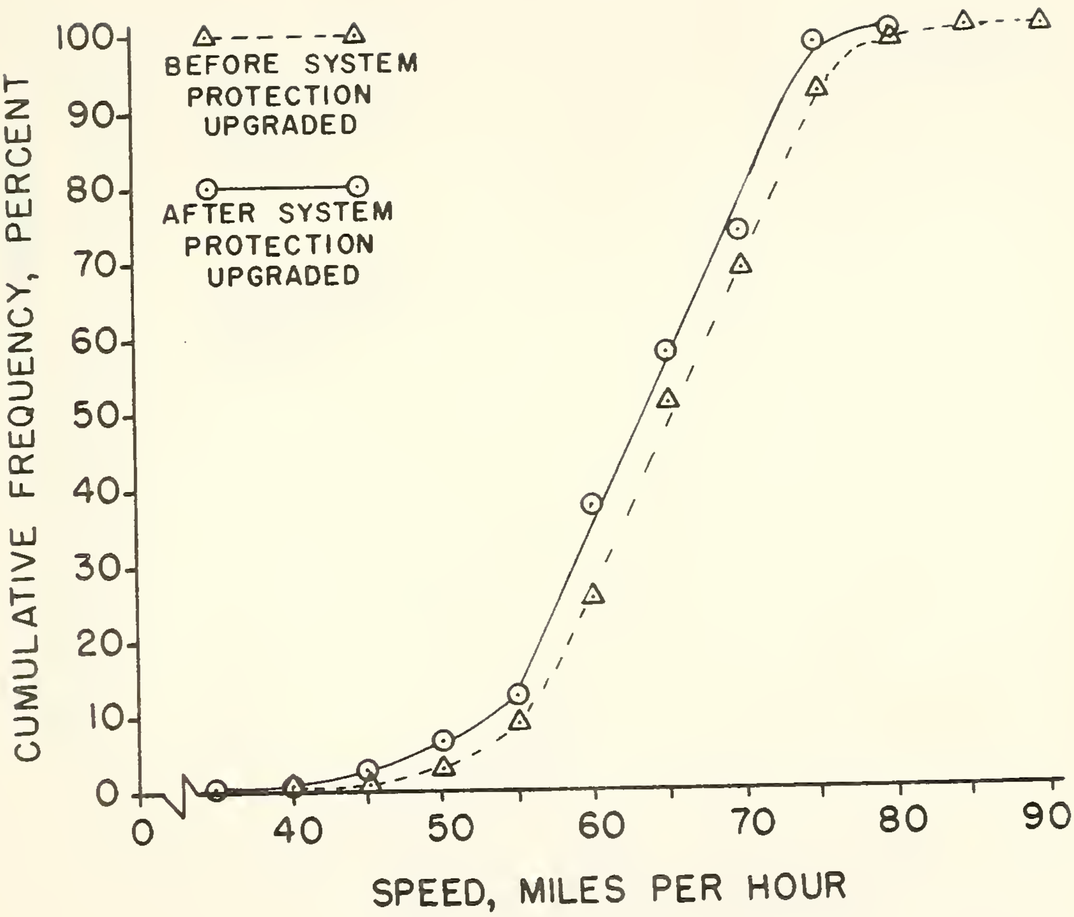

FIGURE 21: CUMULATIVE SPEED DISTRIBUTION CURVE OF BEFORE AND AFTER DATA FOR FREE-FLOW, NORTHBOUND CARS AVERAGED OVER ALL TRAPS

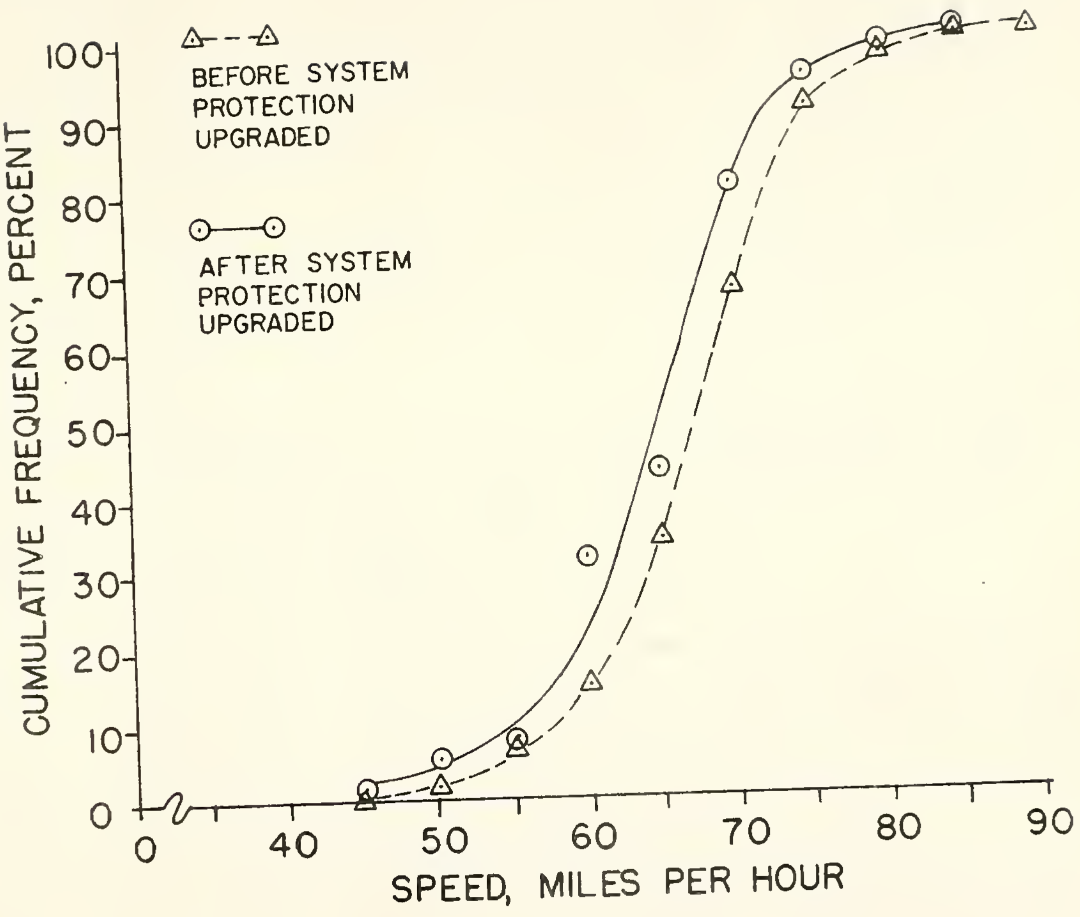

FIGURE 22: CUMULATIVE SPEED DISTRIBUTION CURVE OF BEFORE AND AFTER DATA FOR FREE-FLOW, SOUTHBOUND CARS AVERAGED OVER ALL TRAPS

The reason for this difference could not be determined. The purpose of the above pace analysis was to analyze the affect of some (any) group of "fastest" cars. Since 72 mph is approximately the 85th percentile, it seemed to be a reasonable "break point," to analyze the northbound/southbound, before/after differences of those cars faster than 72 mph. In fact, it seemed more reasonable to use a given speed as a fixed break point because it had already been shown that for <u>any</u> fixed percentile the after speeds were lower than the before speeds.

The summary of above-pace results is shown in Figures 23 and 24 and Tables 18 and 19. It is doubtful that any broad inferences can be drawn from these results but a couple points are of interest. In regard to southbound vehicles, the mean speed profile of these groups is almost identical, but the percentage of cars entering 72 mph after improvement was reduced from 23.6% to 13.6%. This reinforces the implication of greater or earlier awareness of the crossing in the after situation.

The northbound before and after groups had almost equal percentages entering >72 mph, 17.4% vs 17.2%, but the mean speed profile of the after groups was significantly lower in five traps. This lowering indicates a speed reduction of the "fastest" cars.

The fact that a lessor percentage of southbound drivers was traveling greater than 72 after is possibly an indication that they were more aware that there was a grade crossing ahead before entering Trap 1. This cannot be substantiated by other parameters, but it does suggest that research on high speed approaches should have speed traps at distances greater than 1162 feet.

In regard to the significant differences between the before and after northbound, mean-speed profile, this could be an indication that at the Trap 1 location the "speeding" driver (>10 mph above posted speed) became more aware of a crossing ahead, realized that his sight distance was restricted--both directions from the Trap 1 location--and slowed.

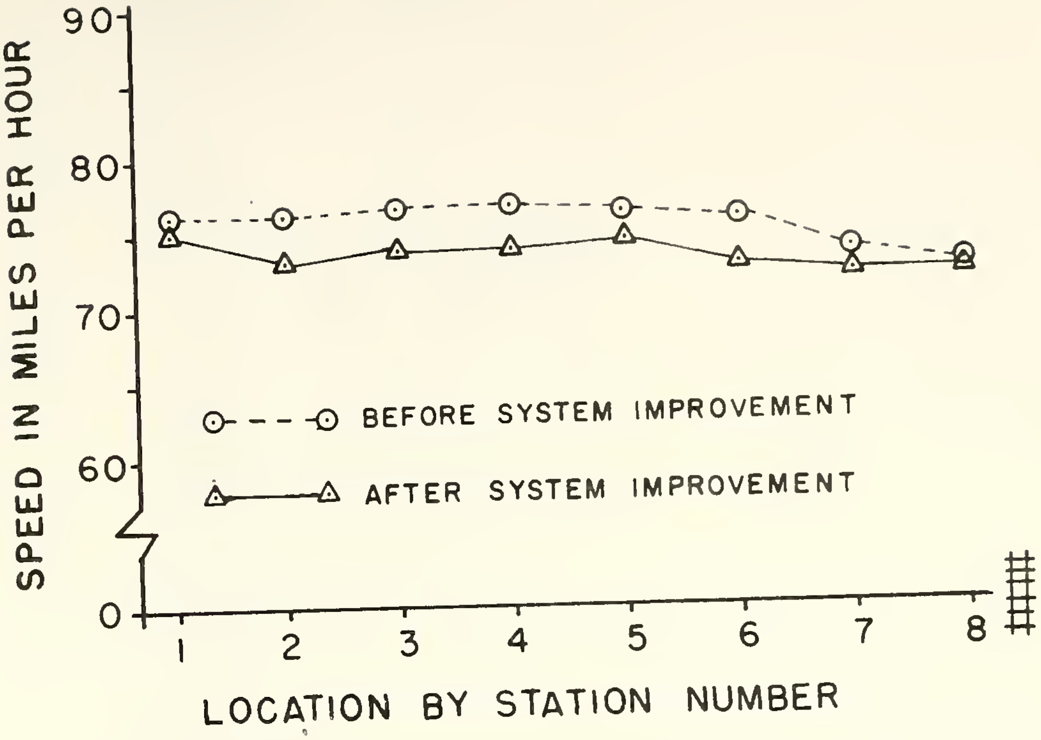

FIGURE 23: SPEED LOCATION GRAPH FOR ABOVE PACE SPEEDS OF FREE-FLOW NORTHBOUND CARS

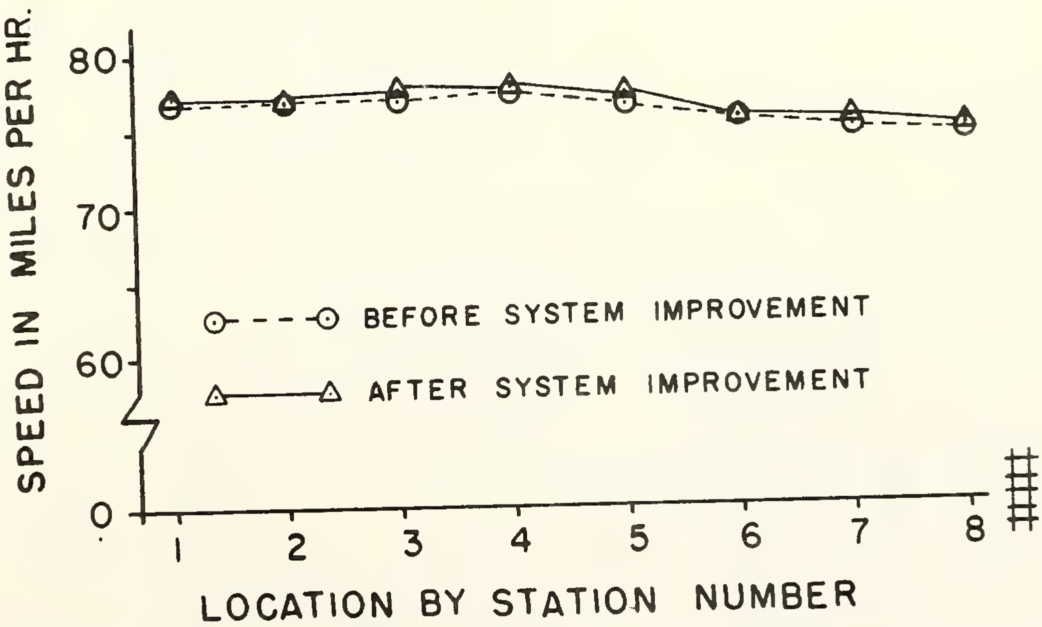

FIGURE 24: SPEED LOCATION GRAPH FOR ABOVE PACE SPEEDS OF FREE-FLOW SOUTHBOUND CARS

TABLE 18. SPEED LOCATION AND DECELERATION - BEFORE AND AFTER COMPARISONS OF ABOVE PACE SPEEDS OF FREE-FLOW CARS NORTHBOUND

VEHICLE CLASSIFICATION PAIRS TESTED FOR SIGNIFICANT DIFFERENCE			MEAN VALUES AT SPEED TRAP LOCATIONS								TABULAR t-VALUES FOR 1 TAIL TEST	
			Trap #1	Trap #2	Trap #3	Trap #4	Trap #5	Trap #6	Trap #7	Trap #8	α	VALUE
1. FREE-FLOW BEFORE	a	SPEED 1 2	76.2 75.0	76.0 72.9**	76.5 73.6**	76.6 73.7**	76.2 74.1*	75.6 72.5*	73.5 72.0	72.4 71.9	0.10	1.305
n_1=24 (17.4%)		t-VALUE	1.21	3.47	2.48	2.69	1.77	2.29	0.85	0.29	0.05	1.686
2. FREE-FLOW AFTER	b	DECEL-ERATION 1 2		0.20 2.12	0.48 0.71	0.12 0.0	0.36 0.41	0.64 1.59	2.00 0.41	0.96 0.12	0.01	2.425
n_2=16 (17.2%)		t-VALUE		-2.74	0.39	-0.23	1.48	-1.18	2.45	1.98		

Notes:

1. Before system improvement
2. After system improvement
3. Pace speed "assumed" 62-72 mph for all cases

a. Speed in miles per hour

b. Deceleration in ft/sec/sec

H_0: $\mu_1 = \mu_2$ / H_1: $\mu_1 > \mu_2$

† Difference significant at $0.10 > \alpha > 0.05$

* Difference significant at $\alpha = 0.05$

** Difference significant at $\alpha = 0.01$

TABLE 19. SPEED LOCATION AND DECELERATION - BEFORE AND AFTER COMPARISONS OF ABOVE PACE SPEEDS OF FREE-FLOW CARS SOUTHBOUND

VEHICLE CLASSIFICATION PAIRS TESTED FOR SIGNIFICANT DIFFERENCE		MEAN VALUES AT SPEED TRAP LOCATIONS Trap #1	Trap #2	Trap #3	Trap #4	Trap #5	Trap #6	Trap #7	Trap #8	TABULAR t-VALUES FOR 1 TAIL TEST α	VALUE
1. FREE-FLOW BEFORE	a SPEED 1	76.8	76.9	76.8	77.2	76.4	75.5	74.8	74.3	0.10	1.303
	2	77.1	77.1	77.6	77.6	77.1	75.6	75.3	74.6	0.05	1.684
n_1=34 (23.6%)	t-VALUE	-0.22	-0.19	-0.52	-0.27	-0.62	-0.10	-0.24	-0.17	0.01	2.423
2. FREE-FLOW AFTER	b DECEL-ERATION 1		0.06	0.02	0.38	0.88	0.91	0.59	0.56		
	2		0.0	0.50	0.0	0.50	1.50	0.38	0.63		
n_2=8 (13.6%)	t-VALUE		0.15	-1.11	0.63	0.59	-0.60	0.25	-0.09		

Notes:

1. Before system improvement
2. After system improvement
3. Pace speed "assumed" 62-72 mph for all cases

a. Speed in miles per hour

b. Deceleration in ft/sec/sec

$H_0: \mu_1 = \mu_2$ / $H_1: \mu_1 > \mu_2$

† Difference significant at $0.10 > \alpha > 0.05$

* Difference significant at $\alpha = 0.05$

** Difference significant at $\alpha = 0.01$

Individual Free-Flow Fastest Vehicles

The individual vehicle speeds comprising the various subsets of northbound and southbound free-flow vehicles entering at >72 mph that make up the means of the groups in Tables 18 and 19 are shown in Tables 20 through 23.

It is of interest to note that these "fastest" drivers are of three distinct types, not apparent when looking only at group means. There are those who decelerate immediately between Trap 1 and Trap 2, there are those who maintain a constant speed until somewhere between Trap 5 and Trap 7 then slow, and finally there are those drivers that maintain a constant speed all the way through the system. Their inconsistencies stand out more than any discernible trend.

Speed Comparisons with Signals Activated

"First" Vehicles

Although there are indications that the unactivated gate arms against the horizon made the presence of a crossing ahead more apparent to approaching motorists than for the before condition, perhaps of more importance is the impact after entry of a train into the system.

In phase I, Butcher categorized the vehicles into first unobstructed, first obstructed, and following (29). As defined earlier, first unobstructed vehicles were first to enter the system after signal activation but did not stop at the crossing because they did not consider the train to be close enough to be a hazard. First obstructed vehicles were the first to enter the system after signal activation and they stopped at the crossing because either the train was across the road or near enough that the driver perceived a danger or an obstruction. Following cars were vehicles that entered the system with the signals activated, train across the road and at least one car already stopped ahead at the crossing. To generalize, each successive category of driver was confronted with additional stimuli upon entry into the system.

TABLE 20. NORTHBOUND FREE-FLOW CARS, BEFORE, ENTERING AT A SPEED >72 MPH

Trap #1 Speed	Trap #2 Speed	Trap #3 Speed	Trap #4 Speed	Trap #5 Speed	Trap #6 Speed	Trap #7 Speed	Trap #8 Speed	Max Decel-eration
90.0	81.8	79.6	79.6	79.6	79.6	79.6	79.6	9.7
81.9	84.1	87.4	84.1	87.4	87.4	84.1	84.1	3.9
81.8	81.8	81.8	79.6	79.6	75.0	73.2	69.2	4.5
81.8	79.6	81.8	81.8	81.8	81.8	79.6	79.6	2.4
79.6	79.6	79.6	79.6	81.8	81.8	81.8	81.8	0.0
79.6	79.6	79.6	79.6	76.9	76.9	75.0	73.2	2.9
75.0	73.2	73.2	73.2	70.9	67.7	57.3	55.2	8.9
75.0	76.9	79.6	79.6	76.9	76.9	76.9	75.0	2.9
75.0	75.0	75.0	75.0	75.0	76.9	76.9	76.9	0.0
75.0	75.0	75.0	75.0	73.2	73.2	67.7	65.7	5.3
75.0	75.0	75.0	75.0	73.2	75.0	70.9	67.7	4.2
75.0	76.9	76.9	79.6	79.6	79.6	76.9	76.9	2.9
75.0	75.0	75.0	75.0	76.9	76.9	76.9	76.9	0.0
75.0	75.0	76.9	76.9	76.9	76.9	76.9	76.9	0.0
75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	0.0
73.2	73.2	70.9	73.2	73.2	73.2	70.9	70.9	2.3
73.2	75.0	81.8	81.8	76.9	76.9	65.7	62.9	11.1
73.2	70.9	69.2	67.7	67.7	64.3	60.0	56.2	3.7
73.2	73.2	73.2	73.2	73.2	73.2	75.0	75.0	0.0
73.2	75.0	76.9	79.6	79.6	79.6	79.6	76.9	2.9
73.2	73.2	73.2	73.2	73.2	70.9	70.9	69.2	2.3
73.2	73.2	73.2	73.2	73.2	73.2	69.2	65.7	3.9
73.2	75.0	75.0	75.0	75.0	73.2	73.2	73.2	1.9
73.2	73.2	73.2	75.0	75.0	73.2	73.2	75.0	1.9

Notes: 1. All values of speed - miles/hour

2. All values of deceleration - ft/sec/sec

TABLE 21. NORTHBOUND FREE-FLOW CARS, AFTER, ENTERING AT A SPEED >72 MPH

Trap #1 Speed	Trap #2 Speed	Trap #3 Speed	Trap #4 Speed	Trap #5 Speed	Trap #6 Speed	Trap #7 Speed	Trap #8 Speed	Maximum Deceleration
75.0	69.2	69.2	69.2	69.2	75.0	72.0	75.0	5.7
75.0	75.0	78.2	75.0	75.0	75.0	75.0	75.0	3.4
75.0	72.0	72.0	72.0	72.0	69.2	69.2	69.2	3.0
75.0	69.2	69.2	69.2	69.2	69.2	66.6	66.6	5.7
75.0	75.0	75.0	75.0	75.0	69.2	69.2	69.2	5.7
75.0	75.0	75.0	78.2	78.2	78.2	78.2	78.2	0.0
75.0	72.0	72.0	72.0	75.0	72.0	72.0	72.0	3.0
75.0	72.0	72.0	75.0	75.0	75.0	75.0	75.0	3.0
75.0	75.0	78.2	78.2	81.8	78.2	78.2	78.2	3.9
75.0	72.0	72.0	69.2	69.2	66.6	64.2	64.2	3.0
75.0	72.0	75.0	75.0	75.0	69.2	69.2	69.2	5.7
75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	3.0
75.0	72.0	75.0	75.0	75.0	75.0	75.0	75.0	3.0
75.0	75.0	72.0	75.0	75.0	75.0	75.0	75.0	3.0
75.0	75.0	75.0	72.0	75.0	69.2	69.2	66.6	5.7
75.0	72.0	72.0	69.2	69.2	69.2	69.2	69.2	3.0

Note: All values of deceleration = ft/sec/sec; speed = miles per hour

TABLE 22. SOUTHBOUND FREE-FLOW CARS, BEFORE, ENTERING AT A SPEED >72 MPH

Trap #1 Speed	Trap #2 Speed	Trap #3 Speed	Trap #4 Speed	Trap #5 Speed	Trap #6 Speed	Trap #7 Speed	Trap #8 Speed	Maximum Decel-eration
87.4	87.4	87.4	87.4	84.1	87.4	84.1	84.1	3.9
81.8	81.8	81.8	81.8	79.6	75.0	75.0	75.0	5.0
81.8	81.8	81.8	81.8	81.8	81.8	79.6	81.8	2.4
81.8	81.8	81.8	81.8	79.6	79.6	79.6	75.0	5.0
81.8	81.8	79.6	84.1	81.8	73.2	69.2	64.3	9.3
79.6	79.6	81.8	79.6	79.6	79.6	79.6	76.9	2.9
79.6	76.9	75.0	76.9	76.9	75.0	75.0	75.0	2.9
79.6	76.9	75.0	75.0	73.2	73.2	73.2	73.2	2.9
79.6	79.6	76.9	75.0	75.0	75.0	73.2	75.0	2.9
79.6	79.6	79.6	76.9	79.6	76.9	75.0	75.0	2.9
79.6	79.6	81.8	81.8	79.6	79.6	79.6	79.6	2.4
79.6	79.6	79.6	81.8	79.6	79.6	81.8	81.8	2.4
76.9	76.9	76.9	76.9	75.0	75.0	76.9	76.9	2.0
76.9	76.9	76.9	76.9	76.9	76.9	76.9	76.9	0.0
76.9	76.9	76.9	79.6	79.6	76.9	75.0	75.0	2.9
75.0	76.9	76.9	76.9	76.9	75.0	76.9	79.6	2.0
75.0	75.0	75.0	75.0	75.0	75.0	75.0	76.9	0.0
75.0	75.0	75.0	76.9	75.0	75.0	75.0	75.0	2.0
75.0	73.2	73.2	73.2	73.2	73.2	73.2	73.2	1.9
75.0	76.9	76.9	76.9	76.9	75.0	70.9	67.7	4.2
75.0	75.0	75.0	76.9	75.0	75.0	75.0	75.0	2.0
75.0	75.0	76.9	76.9	75.0	75.0	75.0	75.0	2.0
75.0	75.0	75.0	73.2	73.2	73.2	73.2	70.9	2.3
75.0	75.0	75.0	75.0	75.0	73.2	75.0	75.0	1.9
75.0	75.0	76.9	76.9	73.2	75.0	73.2	73.2	3.9
73.2	73.2	73.2	75.0	73.2	73.2	75.0	73.2	1.9
73.2	73.2	73.2	73.2	73.2	73.2	73.2	73.2	0.0
73.2	75.0	75.0	75.0	75.0	75.0	75.0	75.0	0.0
73.2	73.2	70.9	73.2	73.2	70.9	73.2	73.2	2.3
73.2	75.0	75.0	75.0	76.9	75.0	69.2	67.7	5.7
73.2	73.2	75.0	76.9	76.9	75.0	76.9	76.9	2.0
73.2	73.2	73.2	73.2	70.9	65.7	61.2	55.2	4.9
73.2	75.0	75.0	73.2	73.2	73.2	73.2	73.2	1.9
73.2	73.2	73.2	73.2	73.2	75.0	73.2	70.9	2.3

Note: 1. All values of speed = miles/hour
2. All values of deceleration - ft/sec/sec

TABLE 23. SOUTHBOUND FREE-FLOW CARS, AFTER, ENTERING AT A SPEED >72 MPH

Trap #1 Speed	Trap #2 Speed	Trap #3 Speed	Trap #4 Speed	Trap #5 Speed	Trap #6 Speed	Trap #7 Speed	Trap #8 Speed	Maximum Deceleration
75.0	75.0	75.0	72.0	75.0	75.0	75.0	78.2	3.0
75.0	75.0	75.0	78.2	78.2	75.0	78.2	75.0	3.4
81.8	81.8	81.8	81.8	81.8	75.0	69.0	66.7	7.4
75.0	75.0	75.0	75.0	75.0	72.0	72.0	69.2	3.0
81.8	81.8	81.8	81.8	81.8	81.8	81.8	81.8	0.0
78.2	78.2	81.8	81.8	78.1	81.8	81.8	81.8	3.9
75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	0.0

Note: All values of deceleration = ft/sec/sec; speed = miles per hour

Two characteristics of the improved system eliminated the "first-unobstructed" group. The improved crossing is always obstructed prior to arrival of a train, after activation of the signal, by the gate arm. Thus, there is no after group that was first unobstructed. The "first obstructed - before" (by train) group was compared to the "first obstructed - after" (by gate arm) group.

The mean speed profile values at the speed-trap locations for "first cars" are shown in Tables 24 and 25 and plotted in Figures 25 and 26. It can be seen in both figures that the first unobstructed group enters at approximately free-flow speed and decelerates rapidly, but not especially drastically, to between 25 to 40 mph, then appears to make the decision that it is safe to cross the tracks ahead of the approaching train. The result of a bad decision here will result in an accident statistic or a "near miss." Automatic gates take the option to cross or not to cross away from all drivers except those very close to the crossing. Taking the option away from the driver eliminates the possibility of a bad decision and, therefore, this particular type of accident statistic.

There are differences in the northbound and southbound "first unobstructed - before" speed profiles. On the southbound approach, drivers slowed to about 40 mph at Trap 7, then appeared to make the decision to cross the tracks. Sight distance on this approach is unobstructed in both directions. On the northbound approach the profile followed practically the same speed pattern up to Trap 7. However, probably due to the restricted sight distance, the northbound, first unobstructed motorist continued to decelerate after Trap 7 to around 27 mph at Trap 8, delaying the decision to cross.

In regard to comparisons related specifically to the effect of the gates, the southbound approach will be considered first. Referring to Figure 25 and Table 24 it can be seen that the "first obstructed - after" (by gate) plots almost identically to the "first obstructed - before" (by train). The t-tests of the means show no significant difference at any trap. This would indicate that the gates were as effective a barrier to the motorist as a train across the highway or

TABLE 24. SPEED LOCATION AND DECELERATION - BEFORE AND AFTER COMPARISONS OF SELECTED CATEGORIES OF ALL SOUTHBOUND CARS

VEHICLE CLASSIFICATION PAIRS TESTED FOR SIGNIFICANT DIFFERENCE			MEAN VALUES AT SPEED TRAP LOCATIONS								TABULAR t-VALUES FOR 1 TAIL TEST	
			Trap #1	Trap #2	Trap #3	Trap #4	Trap #5	Trap #6	Trap #7	Trap #8	α	VALUE
1. FREE FLOW BEFORE, n_1=144	a SPEED	1	68.3	68.3	68.1	68.5	67.5	67.1	66.9	66.3	α=0.10	1.282
		2	66.3*	66.2*	66.4*	66.6*	65.6*	65.5*	65.4*	65.5	α=0.05	1.645
		t-VALUE	1.95	1.87	1.56	1.82	1.76	1.47	1.30	0.72	α=0.01	2.326
2. FREE FLOW AFTER, n_2=59	b DECEL-ERATION	1	0.13	0.11	-0.44	0.83	0.42	0.20	0.47			
		2	0.07	-0.17	-0.14	0.85	0.17	0.07	-0.10			
		t-VALUE	0.30	1.56	-1.61	-0.09	0.94	0.56	2.82			
1. FIRST UNOBSTRUCTED BEFORE, n_1=15	a SPEED	1	67.5	64.9	61.2	58.6	53.1	46.1	39.0	38.6	α=0.10	1.315
		2	58.1**	55.3**	53.0*	49.4**	44.2*	37.9*	22.1**	0.0**	α=0.05	1.706
		t-VALUE	3.25	2.89	2.22	2.34	2.31	2.07	3.39	10.8	α=0.01	2.479
2. FIRST OBSTRUCTED AFTER, n_2=13	b DECEL-ERATION	1	2.07	3.07	1.93	4.27	4.73	4.13	0.20			
		2	2.08	1.62	2.69	3.46	3.62	5.69	4.54			
		t-VALUE	-0.01	2.08	-1.12	1.00	1.07	-1.04	-3.40			
1. FIRST OBSTRUCTED BEFORE, n_1=10	a SPEED	1	61.3	57.8	53.9	48.3	40.7	32.7	22.8	0.0	α=0.10	1.323
		2	58.1	55.3	53.0	49.4	44.2	37.9	22.1	0.0	α=0.05	1.721
		t-VALUE	0.75	0.60	0.20	-0.29	-1.12	-1.97	0.19	0.0	α=0.01	2.518
2. FIRST OBSTRUCTED AFTER, n_2=13	b DECEL-eration	1	2.70	3.10	4.30	4.90	4.10	3.70	4.00			
		2	2.08	1.62	2.69	3.46	3.62	5.69	4.54			
		t-VALUE	1.09	2.05	1.71	1.25	0.46	-1.98	-0.45			
1. FOLLOWING BEFORE, n_1=33	a SPEED	1	48.0	44.6	40.8	36.8	31.1	23.4	13.9	0.0	α=0.10	1.300
		2	49.1	46.0	42.8	39.3	34.5	28.7	11.6	0.0	α=0.05	1.675
		t-VALUE	-0.47	-0.65	-0.93	-1.10	-1.50	-2.16	0.72	0.0	α=0.01	2.394
2. FOLLOWING AFTER, n_2=22	b DECEL-ERATION	1	2.27	2.18	2.00	2.67	2.45	2.63	2.24			
		2	2.04	1.25	2.00	2.54	2.50	4.09	1.82			
		t-VALUE	0.54	0.51	0.0	0.26	-0.09	-2.81	0.78			

TABLE 24. CONTINUED

Notes:

1. Before system improvement
2. After system improvement

a. Speed in miles per hour

b. Deceleration in ft/sec/sec

$H_0: \mu_1 = \mu_2 \ / \ H_1: \mu_1 > \mu_2$

† Difference significant at $0.10 > \alpha > 0.05$

* Difference significant at $\alpha = 0.05$

** Difference significant at $\alpha = 0.01$

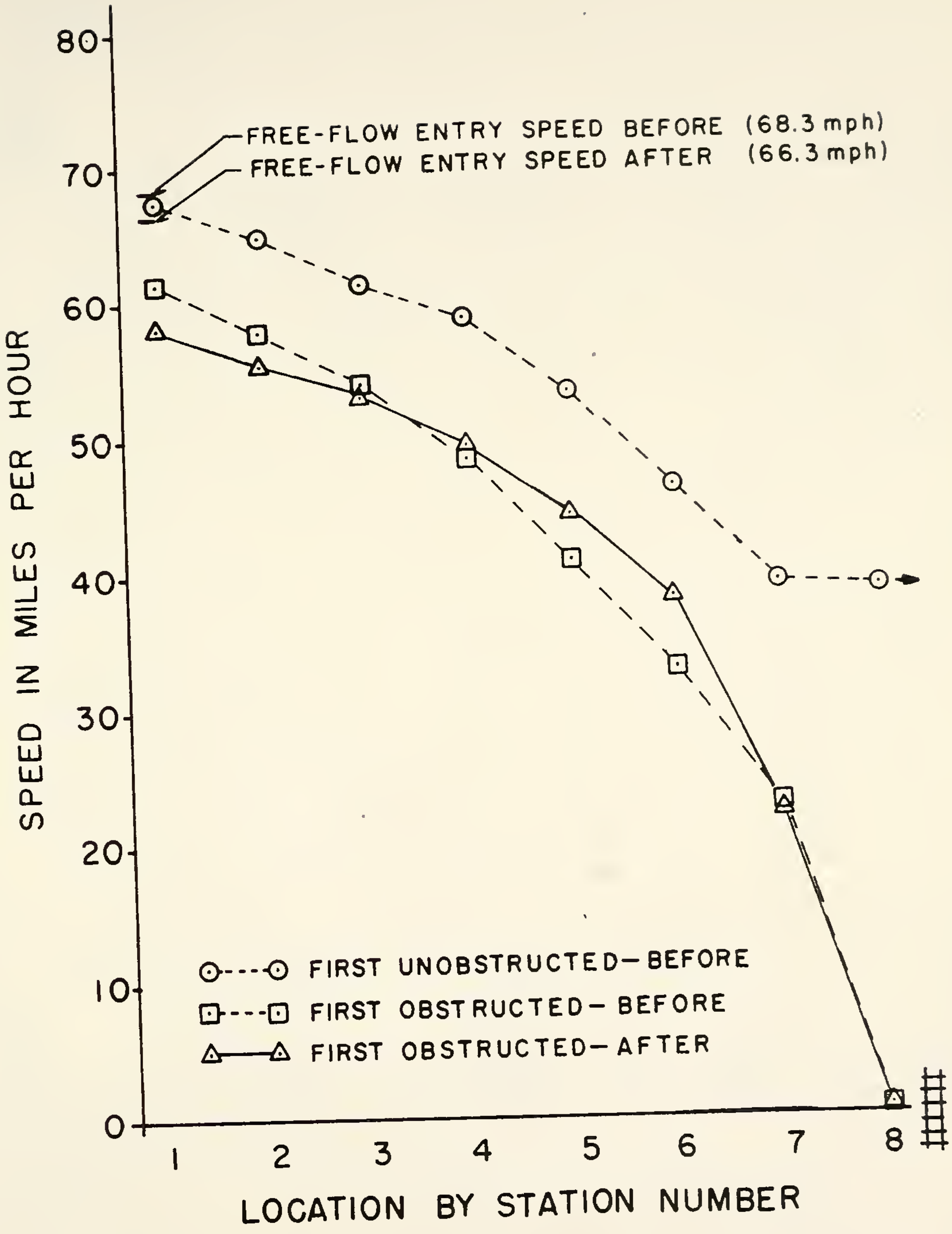

FIGURE 25 SPEED LOCATION GRAPH FOR VARIOUS CATEGORIES OF FIRST SOUTHBOUND CARS

TABLE 25. SPEED LOCATION AND DECELERATION - BEFORE AND AFTER COMPARISONS OF SELECTED CATEGORIES OF ALL NORTHBOUND CARS

VEHICLE CLASSIFICATION PAIRS TESTED FOR SIGNIFICANT DIFFERENCE			MEAN VALUES AT SPEED TRAP LOCATIONS Trap #1	Trap #2	Trap #3	Trap #4	Trap #5	Trap #6	Trap #7	Trap #8	TABULAR t-VALUES FOR 1 TAIL TEST α	VALUE
1. FREE FLOW BEFORE, $n_1=143$	a	SPEED 1	65.7	65.7	66.2	66.2	66.1	65.4	63.8	62.8	α=0.10	1.282
		SPEED 2	65.4	64.7	64.9†	65.2	65.3	64.1	62.8	62.4	α=0.05	1.645
		t-VALUE	0.28	1.19	1.35	1.05	0.77	1.26	0.99	0.37	α=0.01	2.326
2. FREE FLOW AFTER, $n_2=93$	b	DECEL-ERATION 1		-0.06	-0.41	0.01	0.11	0.59	1.3	0.78		
		DECEL-ERATION 2		0.72	-0.29	-0.23	-0.16	1.08	1.1	0.24		
		t-VALUE		-3.91	-0.63	1.28	1.59	-2.11	0.65	2.93		
1. FIRST UNOBSTRUCTED BEFORE, $n_1=15$	a	SPEED 1	64.8	63.4	61.2	57.6	52.7	45.8	36.8	27.2	α=0.10	1.321
		SPEED 2	63.5	61.4	58.7	53.6	48.1*	39.6*	25.6**	0.0**	α=0.05	1.717
		t-VALUE	0.37	0.62	0.80	1.13	1.34	2.17	2.93	6.71	α=0.01	2.508
2. FIRST OBSTRUCTED AFTER, $n_2=9$	b	DECEL-ERATION 1		1.27	1.93	2.93	3.67	4.93	5.13	3.67		
		DECEL-ERATION 2		2.00	2.11	3.89	4.11	5.33	5.78	5.33		
		t-VALUE		-0.74	-0.18	-0.85	-0.49	-0.35	-0.57	-1.27		
1. FIRST OBSTRUCTED BEFORE, $n_1=10$	a	SPEED 1	50.1	48.6	45.8	41.3	36.4	29.2	20.1	0.0	α=0.10	1.333
		SPEED 2	63.5	61.4	58.7	53.6	48.1	39.6	25.6	0.0	α=0.05	1.740
		t-VALUE	-2.20	-2.20	-2.23	-2.32	-2.40	-2.16	-1.17	0.0	α=0.01	2.567
2. FIRST OBSTRUCTED AFTER, $n_2=9$	b	DECEL-ERATION 1		1.1	1.8	3.0	2.7	3.3	3.7	3.2		
		DECEL-ERATION 2		2.0	2.1	3.9	4.1	5.3	5.8	5.3		
		t-VALUE		-0.88	-0.39	-0.76	-1.62	-2.06	-1.64	-1.66		
1. FOLLOWING BEFORE, $n_1=25$	a	SPEED 1	47.3	45.2	43.1	40.6	36.6	30.5	18.8	0.0	α=0.10	1.303
		SPEED 2	49.6	47.1	45.2	41.3	36.5	27.0	11.9*	0.0	α=0.05	1.684
		t-VALUE	-0.71	-0.58	-0.61	-0.23	0.05	1.03	1.85	0.0	α=0.01	2.423
2. FOLLOWING AFTER, $n_2=17$	b	DECEL-ERATION 1		1.24	1.20	1.64	2.08	2.88	3.72	3.32		
		DECEL-ERATION 2		1.41	1.18	2.53	2.59	4.00	4.24	2.00		
		t-VALUE		-0.41	0.04	-1.52	-0.90	-1.70	-0.70	1.74		

TABLE 25. CONTINUED

Notes:

1. Before system improvement
2. After system improvement

a. Speed in miles per hour

b. Deceleration in ft/sec/sec

$H_0: \mu_1 = \mu_2$ / $H_1: \mu_1 > \mu_2$

† Difference significant at $0.10 > \alpha > 0.05$

* Difference significant at $\alpha = 0.05$

** Difference significant at $\alpha = 0.001$

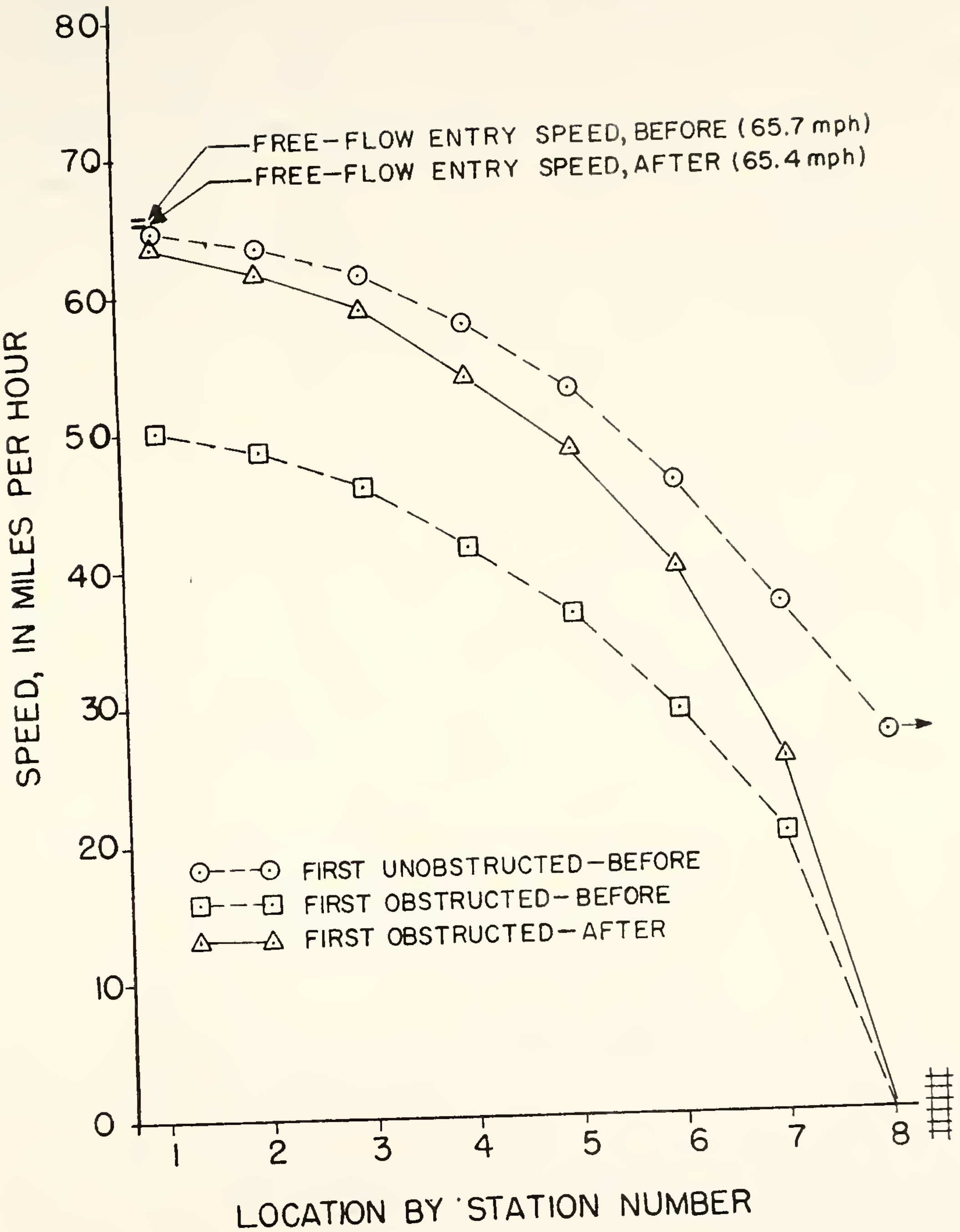

FIGURE 26 SPEED LOCATION GRAPH FOR VARIOUS CATEGORIES OF FIRST NORTHBOUND CARS

very near the crossing. Also, note that the entry speeds are both significantly lower than free-flow car entry speed. The slower entry speeds indicate that on this approach with its unrestricted sight distance, the signals and/or train possibly had an affect on approaching drivers farther from the crossing than the first trap (>1162.5 feet).

One aspect of the new system cannot adequately be evaluated with the data obtained. With the Marquardt speed predictor activating the signals a uniform 20-25 seconds before the train reached the crossing, the train was at times visible to an alert southbound motorist several seconds before the signals were activated and while the driver was still several hundred feet from the crossing. There was no way to separate from the data which, if any, of the drivers saw a train before signal activation and which ones were motivated by the signals only.

On the northbound approach, statistical analysis and plots of "first obstructed - before" vs. "first obstructed - after" are quite different. The "first obstructed - after" more closely follows the "first unobstructed - before." Although the mean speed of the after group is less than "first unobstructed - before" at all traps, the difference is not statistically significant until the fifth trap. From that point (542.4 feet), the difference is significant as motorists decelerate rapidly to a stop in the after situation.

Even though the affect of gates on the northbound approach does not appear to be as analogous to train presence (first obstructed - before) as it does on the southbound approach, a comparison of the group mean values of southbound and northbound "first obstructed - after," shows that from the 5th through 8th traps they are about the same. Other data indicate that free-flow vehicles on the northbound approach appear to delay their reaction to the crossing until reaching the vicinity of Trap 5, for reasons that may not be a function of protection type.

The relatively large difference of higher entry speeds of "first obstructed - after" vs. "first obstructed - before" does not necessarily negate the hypothesis that gates have a similar obstructing affect as a train across the road. In the case of the northbound approach, the lower "first obstructed - before" mean speeds could be due to the

existence of some unusually slow vehicles in the small sample, possibly due to drivers seeing the train and signals and slowing prior to Trap 1. Some indication of this point may be observed from the Interim Report data (Ref. 29, Figure 22, p. 99 and Figure 26, p. 108) which show that the range of speeds for southbound, first obstructed cars is 47-80 mph while the range for northbound, first obstructed car speeds is 28-82 mph. These southbound and northbound distributions are shown in Figures 27 and 28, respectively.

Following Vehicles

Data on following vehicles, northbound/southbound, before/after were also analyzed. As can be noted by examination of Tables 24 and 25 and observed in Figure 29 the data show no meaningful differences due to the improved signal system in either direction of approach. The obvious conclusion is that following vehicles are primarily affected by other vehicles stopped ahead.

Fastest Vehicles After Signal Activation

Previously, an analysis of free-flow vehicles above the pace (above 72 mph) was made by looking at the group means as well as a listing of the vehicles making up these groups. The fastest cars entering the system under other than free-flow conditions were also studied.

On the northbound approach the fastest entering cars are listed in Tables 26 and 27 for before and after data respectively. On the southbound approach the fastest entering cars are listed in Tables 28 and 29 for before and after data respectively.

After signal improvements, the fastest of the southbound cars were slower than the fastest northbound cars even though the free-flow southbound group mean was faster. This adds support to the hypothesis that the southbound motorist becomes aware of the signal or train prior to entry into the system although the data do not show this effect on the northbound motorist. Groups 1 and 4 of after vehicles entered

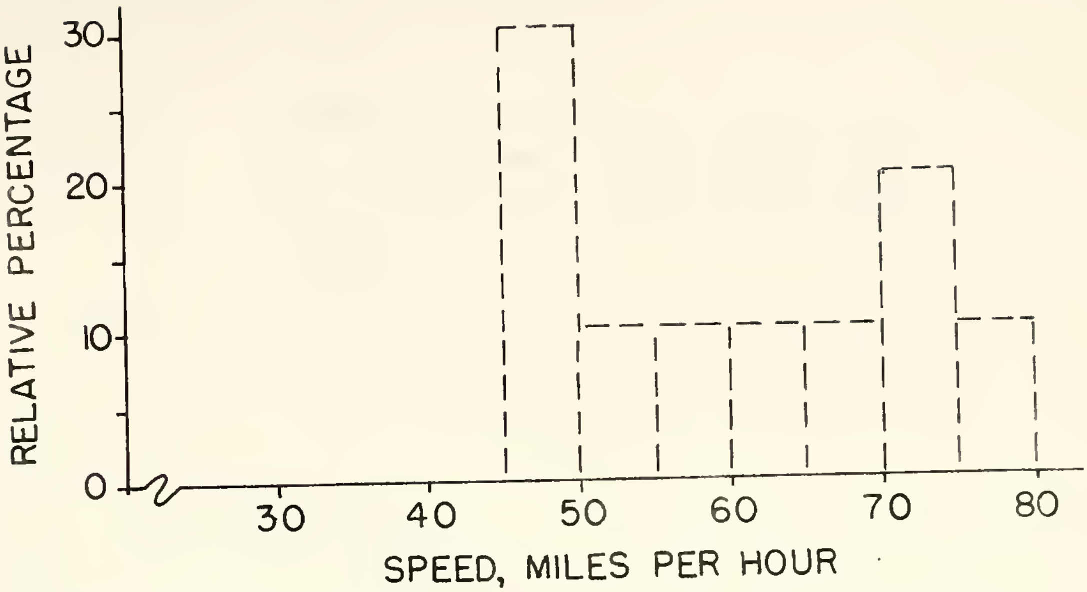

FIGURE 27 SOUTHBOUND MEAN SPEED DISTRIBUTION AT TRAP NO. 1 FOR FIRST OBSTRUCTED CARS — BEFORE

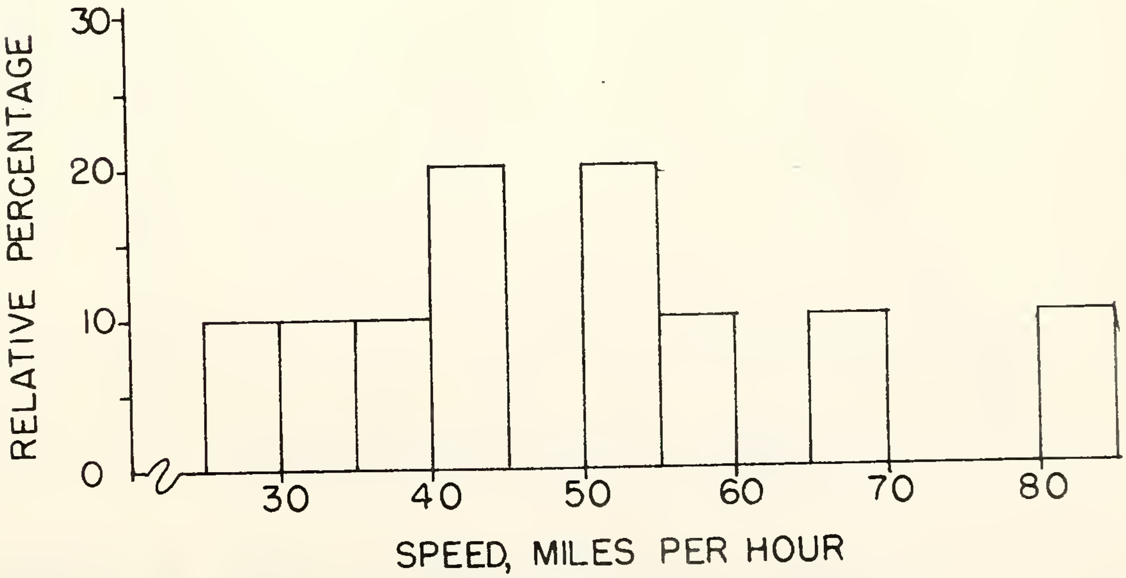

FIGURE 28 NORTHBOUND MEAN SPEED DISTRIBUTION AT TRAP NO. 1 FOR FIRST OBSTRUCTED CARS — BEFORE

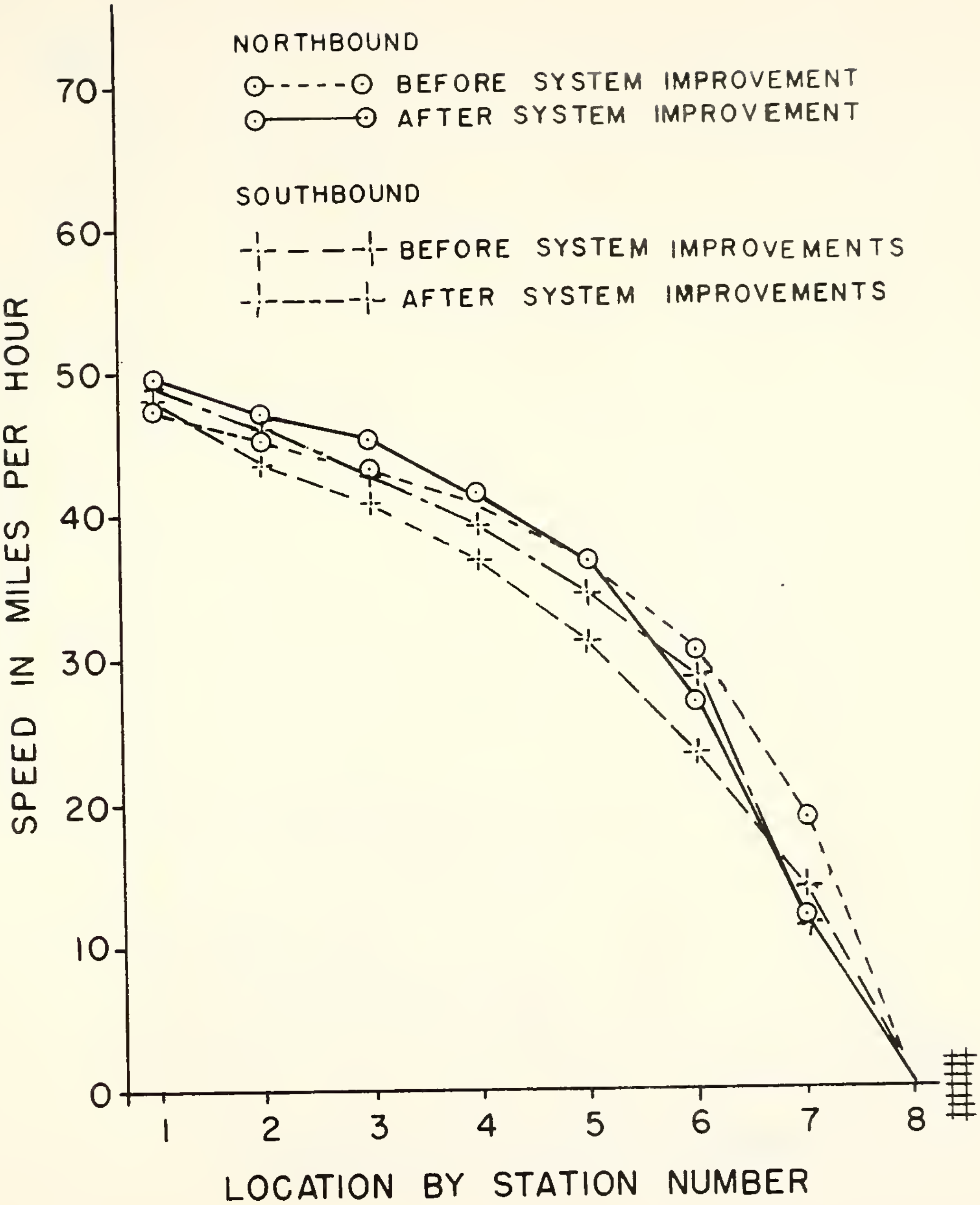

FIGURE 29 SPEED LOCATION GRAPH FOR FOLLOWING CARS-BOTH DIRECTIONS

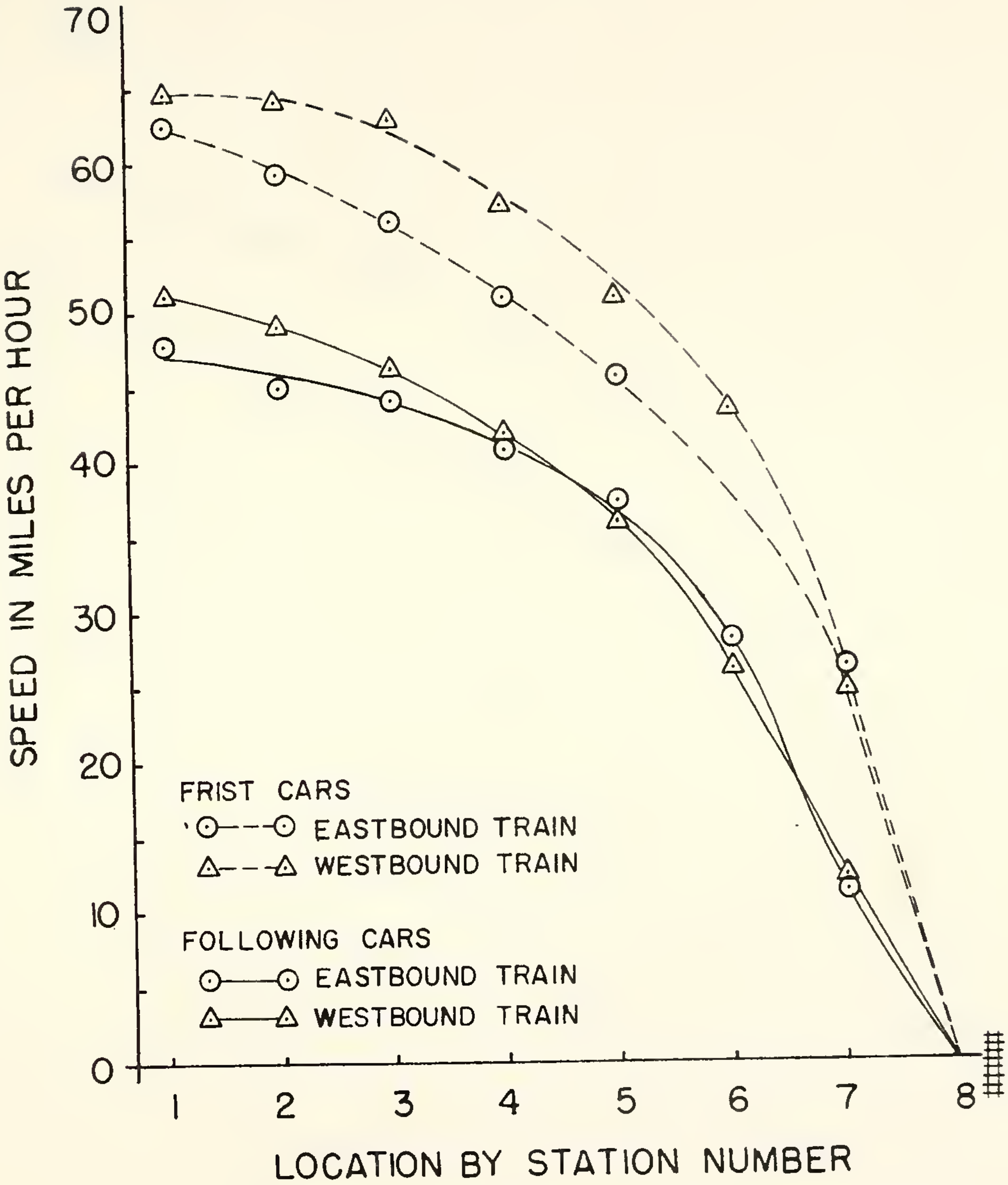

FIGURE 30 NORTHBOUND CARS AS A FUNCTION OF TRAIN DIRECTION (AFTER IMPROVEMENT)

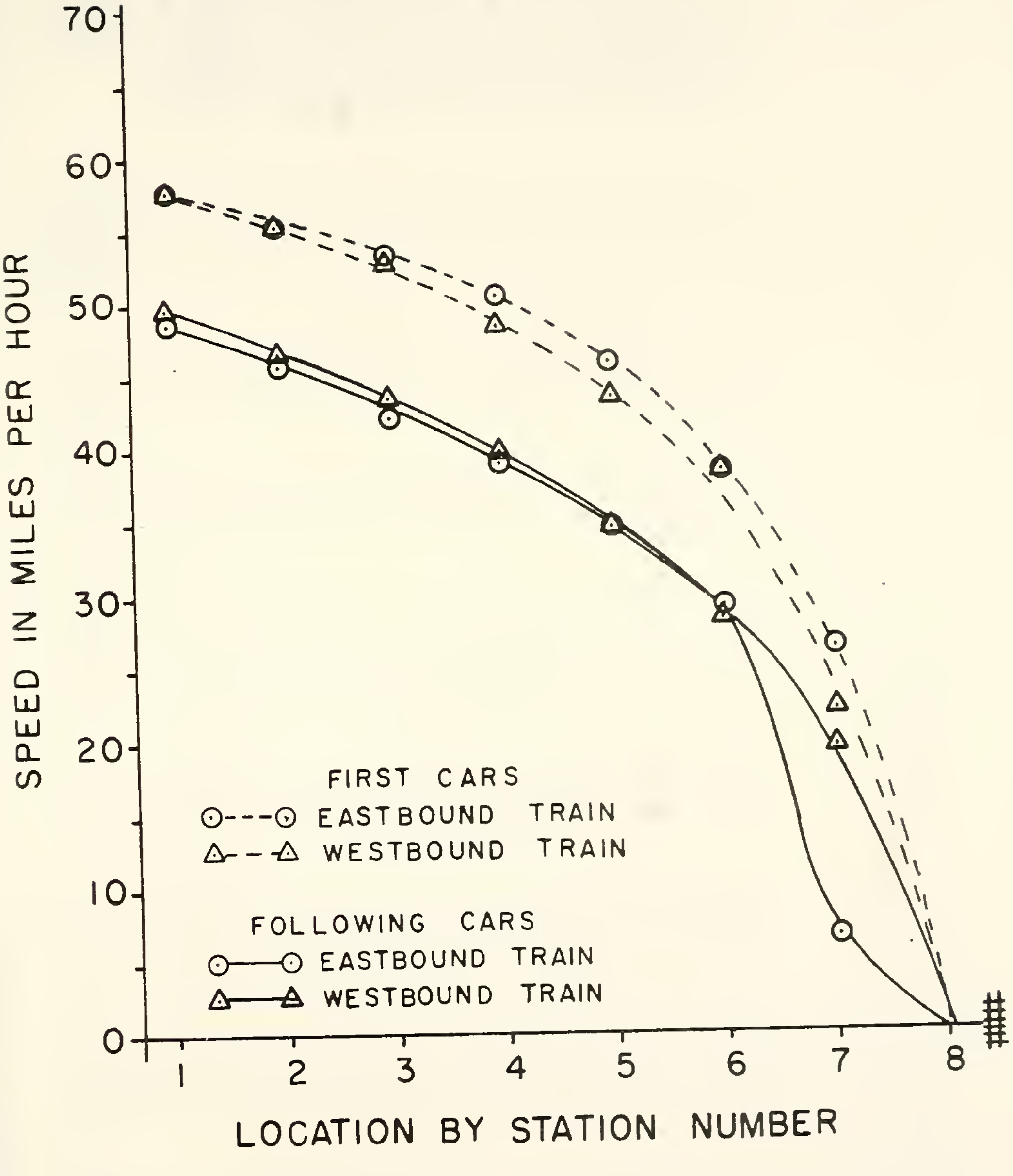

FIGURE 31 SOUTHBOUND CARS AS A FUNCTION OF TRAIN DIRECTION (AFTER IMPROVEMENT)

TABLE 26. NORTHBOUND CARS FROM OTHER THAN FREE-FLOW GROUP, BEFORE, ENTERING AT A SPEED >65 MPH

Trap #1 Speed	Trap #2 Speed	Trap #3 Speed	Trap #4 Speed	Trap #5 Speed	Trap #6 Speed	Trap #7 Speed	Trap #8 Speed	MAXIMUM DECEL-ERATION	TYPE GROUP
87.4	87.4	81.8	79.6	67.7	56.3	39.6	44.3	12.2	FIRST UNOBSTRUCTED
79.6	76.9	73.2	64.3	50.0	39.1	31.0	0.0	11.3	FIRST OBSTRUCTED
76.9	72.0	70.9	73.2	70.9	67.7	47.4	33.0	16.2	FIRST UNOBSTRUCTED
76.9	76.9	75.0	69.2	64.3	60.0	56.3	52.0	5.7	FIRST UNOBSTRUCTED
73.2	69.2	62.9	55.2	47.4	35.0	20.5	0.0	7.0	FIRST OBSTRUCTED
73.2	70.9	67.7	58.8	45.7	32.1	20.9	0.0	9.5	FIRST OBSTRUCTED
70.9	67.7	64.3	60.0	55.2	50.0	45.0	45.0	3.8	FIRST UNOBSTRUCTED
70.9	70.9	69.2	70.9	67.7	62.9	55.2	55.2	6.3	FIRST UNOBSTRUCTED
69.2	67.7	62.9	61.2	56.3	55.2	56.3	56.3	4.3	FIRST UNOBSTRUCTED
69.2	67.7	62.9	55.2	45.7	40.4	29.0	0.0	6.6	FIRST OBSTRUCTED
69.2	64.3	55.2	47.4	37.5	0.0	0.0	0.0	9.7	FOLLOWING
67.7	61.2	52.0	39.1	29.0	25.7	20.9	0.0	8.1	FOLLOWING
67.7	62.9	56.3	52.0	46.6	38.6	33.3	40.4	5.5	FOLLOWING

Notes:

1. All values of speed = miles/hour
2. All values of deceleration = ft/sec/sec

TABLE 27. NORTHBOUND CARS FROM OTHER THAN FREE-FLOW GROUP, AFTER, ALL CARS ENTERING AT A SPEED $\geq$60 MPH

Trap #1 Speed	Trap #2 Speed	Trap #3 Speed	Trap #4 Speed	Trap #5 Speed	Trap #6 Speed	Trap #7 Speed	Trap #8 Speed	MAXIMUM DECEL-ERATION	ORIG. TYPE GROUP	FINAL TYPE GROUP	
75.0	69.2	66.7	64.2	60.0	47.3	39.1	0.0	10.6	1	1	FIRST OBSTRUCTED
75.0	72.0	64.3	64.3	56.2	50.0	34.6	0.0	8.9	1	1	FIRST OBSTRUCTED
75.0	69.2	66.6	60.0	52.9	40.9	28.1	0.0	7.8	4	1	FIRST OBSTRUCTED
60.0	60.0	60.0	52.9	40.9	28.1	31.0	0.0	6.6	3	1	FIRST OBSTRUCTED
62.1	64.3	64.3	56.3	50.0	41.8	33.3	0.0	7.7	2	1	FIRST OBSTRUCTED
62.1	60.0	60.0	54.5	47.4	39.1	0.0	0.0	10.6	4	1	FIRST OBSTRUCTED
64.2	64.2	60.0	60.0	58.0	50.0	33.3	0.0	9.6	7	2	FOLLOWING
64.3	64.3	64.3	60.0	51.4	39.1	23.1	0.0	7.7	7	2	FOLLOWING
64.3	64.3	64.3	54.5	47.3	36.0	0.0	0.0	8.9	7	2	FOLLOWING
60.0	56.2	56.2	50.0	43.9	34.0	20.9	0.0	5.3	7	2	FOLLOWING
60.0	56.3	50.0	47.4	39.1	30.0	15.8	0.0	4.6	5	2	FOLLOWING

Notes:

1. All values of speed = miles/hour
2. All values of deceleration - ft/sec/sec

TABLE 28. SOUTHBOUND CARS FROM OTHER THAN FREE-FLOW GROUP, BEFORE, ENTERING AT A SPEED >65 MPH

Trap #1 Speed	Trap #2 Speed	Trap #3 Speed	Trap #4 Speed	Trap #5 Speed	Trap #6 Speed	Trap #7 Speed	Trap #8 Speed	MAXIMUM DECEL-ERATION	TYPE GROUP
81.8	81.8	79.6	70.9	62.9	52.9	35.0	0.0	10.9	FIRST OBSTRUCTED
75.0	73.2	69.2	73.2	64.3	52.0	37.5	18.8	9.8	FIRST UNOBSTRUCTED
75.0	67.7	60.0	52.9	43.5	37.0	27.3	23.1	7.2	FIRST UNOBSTRUCTED
73.2	73.2	69.2	69.2	55.2	49.2	42.9	34.2	6.3	FIRST UNOBSTRUCTED
69.2	69.2	64.3	60.0	55.2	50.0	42.9	39.1	4.6	FIRST UNOBSTRUCTED
69.2	67.7	67.7	65.7	64.3	55.2	44.3	35.6	7.5	FIRST UNOBSTRUCTED
69.2	67.7	60.0	52.9	44.3	33.3	17.3	0.0	6.8	FIRST OBSTRUCTED
67.7	65.7	65.7	60.0	53.9	50.0	49.2	47.4	4.9	FIRST UNOBSTRUCTED
65.7	60.0	56.3	49.2	42.9	31.8	22.1	0.0	5.7	FIRST OBSTRUCTED

Notes:

1. All values of speed = miles/hour
2. All values of deceleration - ft/sec/sec

TABLE 29. SOUTHBOUND CARS FROM OTHER THAN FREE-FLOW GROUP, AFTER, ENTERING AT A SPEED $\geq$60 MPH

Trap #1 Speed	Trap #2 Speed	Trap #3 Speed	Trap #4 Speed	Trap #5 Speed	Trap #6 Speed	Trap #7 Speed	Trap #8 Speed	MAXIMUM DECEL-ERATION	ORIG. TYPE GROUP	FINAL TYPE GROUP	
64.2	64.2	64.2	60.0	52.9	42.8	31.0	0.0	6.7	1	1	FIRST OBSTRUCTED
64.2	64.2	62.1	58.1	52.9	45.0	32.1	0.0	6.8	4	1	FIRST OBSTRUCTED
64.2	58.0	65.2	50.0	40.9	32.1	0.0	0.0	5.7	2	1	FIRST OBSTRUCTED
64.2	60.0	60.0	56.2	50.0	46.1	36.0	0.0	8.9	1	1	FIRST OBSTRUCTED
60.0	58.0	54.5	50.0	45.0	45.0	24.3	0.0	9.9	3	1	FIRST OBSTRUCTED
60.0	58.0	54.5	50.0	45.0	45.0	24.3	0.0	9.9	3	1	FIRST OBSTRUCTED
60.0	56.2	56.2	58.0	54.5	42.8	39.1	0.0	7.8	4	1	FIRST OBSTRUCTED
60.0	60.0	60.0	56.2	50.0	36.0	0.0	0.0	8.9	1	1	FIRST OBSTRUCTED
60.0	56.2	56.2	47.3	40.9	29.0	16.3	0.0	5.7	7	2	FOLLOWING
60.0	65.2	52.9	50.0	42.8	34.6	25.0	0.0	4.6	5	2	FOLLOWING
60.0	60.0	54.2	47.3	37.5	28.1	16.9	0.0	5.7	5	2	FOLLOWING

Notes:

1. All values of speed = miles/hour
2. All values of deceleration - ft/sec/sec

Trap 1 at signal activation. Any prior slowing would not have been from the signals but could have been from sighting a train. On the northbound approach at Trap 1, it was impossible to see an eastbound train before it activated the signal and very unlikely that a westbound train would be seen. The implication is that sighting of a train along with signal activation, leaving no doubt regarding signal credibility, had the greatest effect on the group of "fastest" cars.

Table 30 shows the percentage of cars of each sample which entered the before and after systems above 60 mph. The percentage reduction of these "high" speeds appears to be significant. The summary table shows clearly that in all categories of both southbound and northbound cars, the percentage of high-speed cars shows reductions in all northbound cases >75 mph and all southbound cases >65 mph. The reduction in the percentage of cars traveling >65 mph was greater on the southbound approach than on the northbound approach for both conditions, "free-flow" and "signals activated." Possible reasons for this are as follows.

These speeds are at entry and it has been previously noted that slowing down occurs closer to the track on the northbound approach than on the southbound approach, and it should be kept in mind that these entry speeds are 1165 feet from the crossing.

Secondly, with the Marquardt speed predictor, the train would generally be visible to southbound motorists at the time of or soon after signal activation, thus, there is no doubt regarding the credibility of the warning. In the "before" cases where there were warnings up to 90 seconds before the train's arrival this was not always the case.

One innovation was added to this particular automatic gate installation. Strobe lights, described previously, had been added to each gate arm. By constant observation during an entire summer and by conversations with visitors to the site, the strobe lights were probably the most impressive signal feature of the new system. These high-intensity flashing lights were visible several thousand feet from the crossing. Even though a driver may not know what was ahead, he was alerted to the flashes.

The strobe lights should be equally visible to northbound and southbound motorists and; therefore, should be equally effective.

TABLE 30. SUMMARY OF FASTEST CARS, BEFORE AND AFTER, AS A PERCENT[1] OF THEIR TOTAL SAMPLE

NORTHBOUND

	SIGNALS ACTIVATED		FREE-FLOW	
	BEFORE	AFTER	BEFORE	AFTER
% > 60 MPH	26	42	50	68
% > 65 MPH	26	12	23	49
% > 72 MPH	12	12	18	16
% > 75 MPH	8	0	5	0
% > 80 MPH	2	0	2	0
% > 85 MPH	2	0	1	0

SOUTHBOUND

	SIGNALS ACTIVATED		FREE-FLOW	
	BEFORE	AFTER	BEFORE	AFTER
% > 60 MPH	19	31	92	75
% > 65 MPH	19	0	73	59
% > 72 MPH	7	0	26	14
% > 75 MPH	2	0	10	5
% > 80 MPH	2	0	3	3
% > 85 MPH	0	0	0	0

Note:

1. Percentage to nearest whole number

However, the southbound approach differs from the northbound approach as previously discussed, i.e., because of its more open, "freeway type" approach and drivers less expectant of obstructions, the reaction to them would be more noticeable when comparing before and after conditions. In other words, because of higher driver expectancy, northbound drivers had been more aware of the old signals than southbound drivers. Thus, the change after signal improvement could have had more effect on the southbound driver.

The reduction in southbound free-flow vehicle speeds prior to entry obviously could not be from the strobe lights. However, by personal observation, the gate arms themselves, hanging in the air against the horizon, make a southbound motorist more aware that "something" is ahead even if not recognized as a grade crossing. Some drivers slow down for grade crossings because of expected roughness even if they have no concern for a train. Drivers also tend to slow for unrecognizable "somethings" ahead.

Other aspects of the improved visibility of the grade crossing warning system after improvement, are discussed in a later section which contains a detailed discussion of visual conditions and their effect on drivers.

The Effect of Train Direction

Visibility down the tracks is good in both directions on the southbound approach. On the northbound approach there is a severe sight restriction to the west making it impossible to see an eastbound train clearly until the train is approximately 200 feet from the highway. A westbound train, on the other hand, is visible to a northbound driver at least one half mile from the crossing while the driver is still about 800 feet from the tracks.

The after data were coded so that train direction could be analyzed as one of the variables. This was not done with the before data, thus no before and after comparisons could be made. Splitting the already small first-obstructed car sample by train direction, however, resulted in samples too small for making broad inferences.

TABLE 31. SPEED LOCATION COMPARISONS OF THE EFFECT OF TRAIN DIRECTION ON MEAN SPEEDS OF NORTHBOUND AND SOUTHBOUND FIRST CARS

VEHICLE CLASSIFICATION PAIRS TESTED FOR SIGNIFICANT DIFFERENCE[2]		MEAN VALUES[1] AT SPEED TRAP LOCATIONS								TABLE VALUES FOR 1-TAIL t-TEST	
		Trap #1 Speed	Trap #2 Speed	Trap #3 Speed	Trap #4 Speed	Trap #5 Speed	Trap #6 Speed	Trap #7 Speed	Trap #8 Speed		
NORTHBOUND FIRST CARS $n_1=5$, $n_2=4$	1 EASTBOUND TRAIN 2 WESTBOUND TRAIN t-VALUE	62.5 64.8 0.34	59.3 64.1 0.87	56.0 62.1 1.17	50.8 57.0 1.01	45.7 50.9 0.91	36.9 42.9 1.39	26.4 24.7 -0.20	0.0 0.0 0.0	α=0.10 α=0.05 α=0.01	1.415 1.895 2.998
SOUTHBOUND FIRST CARS $n_1=6$, $n_2=6$	1 EASTBOUND TRAIN 2 WESTBOUND TRAIN t-VALUE	57.7 57.5 -0.05	54.8 55.2 0.08	52.9 52.5 -0.08	50.3 48.3 -0.38	45.6 43.2 -0.48	38.6 38.2 -0.11	26.2 21.6 -0.62	0.0 0.0 0.0	α=0.10 α=0.05 α=0.01	1.372 1.812 2.764

Notes:

1. Speed in miles per hour
2. $H_0: \mu_1 = \mu_2$ / $H_1: \mu_1 < \mu_2$
   Difference significant at $0.10 > \alpha > 0.05$

* Difference significant at $\alpha = 0.05$

** Difference significant at $\alpha = 0.01$

It can be seen in Table 31 that a one-tailed t-test of mean approach speeds does not show any significant differences. However, the small sample sizes need very large differences to be statistically significant.

A plot of the data for both the northbound and southbound approaches is shown in Figures 30 and 31. Note that on the southbound approach where the train is visible from both directions, the plot of mean approach speeds data is almost identical for the two train directions. However, on the northbound approach a plot of mean approach speeds shows that when the train is eastbound and cannot be seen by the motorists, their speeds are several mph slower between Trap 2 and Trap 6. Intuitively, it seems that such slower speed is contrary to what one would expect. That is, visibility of the train plus gates should have more effect on slowing a driver than just gates. In any event, on either approach, there is no evidence that gates alone are any less effective than when the train itself is visible.

Analysis of Deceleration Rates

Brief Review of Phase I

From the phase I data seven deceleration rates, one between each trap, were calculated for each of the 520 observed vehicles by the equation previously derived. The 3640 deceleration rates (520 vehicles × 7 locations between traps) were placed into the classifications 1 through 5 as previously discussed.

Only 20 deceleration rates from 13 vehicles were above classification 1, as shown in Table 32.

TABLE 32. SUMMARY OF HIGH DECELERATION RATES - BEFORE

Classification	Name	Number
2	undesirable	17
3	uncomfortable	2
4	very uncomfortable	1

TABLE 33. SUMMARY OF VEHICLES EXHIBITING DECELERATION RATE HIGHER THAN THE COMFORTABLE RANGE BEFORE IMPROVEMENT (Source: Ref. 29, p. 111)

VEHICLE CATEGORY	OVERALL MEAN ENTRY SPEED	VEHICLE ENTRY SPEED	CLASS OF DECELERATION RATE BETWEEN STATIONS						
			1&2	2&3	3&4	4&5	5&6	6&7	7&8
S.B. FF Trucks									
None									
N.B. FF Trucks									
None									
S.B. FF Cars									
Veh. 1	68.4	81.8	1	1	1	1	2	1	1
N.B. FF CARS	65.6								
Veh. 1		73.0	1	1	1	1	1	2	1
Veh. 2		75.0	1	1	1	1	1	2	1
Veh. 3		90.0	2	1	1	1	1	1	1
S.B. 1st Unobs. Cars	67.5								
Veh. 1		67.5	1	1	1	1	2	1	1
Veh. 2		87.1	1	1	1	3	2	2	1
Veh. 3		77.1	1	1	1	1	1	4	2
N.B. 1st Unobs. Cars	64.7								
Veh. 1		75.0	1	1	1	2	2	2	1
Veh. 2		60.0	1	1	1	1	1	2	1
Veh. 3		69.2	1	1	1	1	2	1	1
S.B. 1st Obs. Cars	61.2								
Veh. 1		73.0	1	1	1	2	1	1	1
Veh. 2		79.4	1	1	2	3	1	1	1
N.B. 1st Obs. Cars									
Veh. 1	50.3	81.8	1	1	2	1	1	2	1
S.B. Following Cars									
None									
N.B. Following Cars									
None									

TABLE 34. SUMMARY OF VEHICLES EXHIBITING A DECELERATION RATE HIGHER THAN THE COMFORTABLE RANGE AFTER IMPROVEMENT

VEHICLE CATEGORY	GROUP MEAN ENTRY SPEED	VEHICLE ENTRY SPEED	CLASS OF DECELERATION RATE BETWEEN STATIONS						
			1&2	2&3	3&4	4&5	5&6	6&7	7&8
N.B. Truck None									
First Obstructed Truck	*	60.0	1	1	1	1	2	1	1
Following Truck	*	56.2	1	1	1	1	1	2	1
First Obstructed N.B. Car 1. 2.	63.5 63.5	75.0 62.1	1 1	1 1	1 1	1 1	2 1	1 2	2 1
Following Car	64.3	49.6	1	1	1	1	1	2	1
First Obstructed S.B. Car 1. 2. 3.	58.1 58.1 58.1	60.0 60.0 60.0	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	2 2 1	1 1 2

* Not calculated

Many, if not all, of the motorists in the "undesirable" classification (2), with limits 8 through 11 feet/sec/sec may have decelerated at this rate normally. The Traffic Engineering Handbook describes it as, "undesirable but not alarming to passengers." If one assumes that deceleration rates in groups three and four resulted because these motorists did not become aware of the train until late in their approach, and this is not necessarily so, the rate of such motorists might be a measure of the effectiveness of warning systems.

Analysis of the phase II data showed that there were only nine deceleration rates from eight vehicles out of 1827 rates (261 vehicles × 7 locations) that were above classification 1. Tables 33 and 34 show the vehicle deceleration patterns for those vehicles which had a deceleration rate greater than class 1 for the before and after studies respectively.

Table 35 is a summary of the high deceleration rates after the improvement.

TABLE 35. SUMMARY OF HIGH DECELERATION RATES - AFTER

Classification	Name	Number
2	undesirable	9
3	uncomfortable	0
4	very uncomfortable	0

It can be seen that there were no rates above the undesirable range after system improvement. The extremely small number of such high deceleration rates, however, did not permit their use as a measure of system effectiveness in this study. A much larger sample of before and after motorists would have been necessary to provide any conclusive evidence.

Factors Affecting Visual Acuity

The Voorhees Report (13, Appendix B) contains a very comprehensive review of human factors research. Several findings from this human factors literature will be presented in this section and related to visual conditions at the Goldsmith grade crossing (13).

It appears on first examination of the Goldsmith grade crossing site that the only sight restriction is in the southwest quadrant and that sight distance, particularly for a southbound motorist, is excellent. However, the accident history shows that most of the fatal accidents involved southbound drivers. The visibility of trains on the southbound approach, in reality, only appears to be good, as the lack of contrast between dark trains and the dark background might well cause a motorist to not see the train. This condition probably is present at many other grade crossings to some degree and should be given more attention.

One factor in a driver's visual environment that must be considered is that a driver's reactions are dependent not only on his basic visual capabilities but also on the degree to which they are utilized at any given time (13, p. 83). Thus, no matter what the level of a driver's visual acuity, there are times he is not using it up to his capabilities.

A person's ability to differentiate colors is interrelated with the brightness variable and lessens as illumination decreases (13, p. 84). The greater the contrast an object has with its background the more legible the object (13, p. 84). Low illumination levels decrease the visual powers of acuity, contrast, form perception, depth perception, and the ability to judge size, motion and position (13, p. 84).

There are conditions where the natural background is very important to signs and signals. An example would be at dusk when the sky is still bright but road-level objects merge with a dark, shadowy background, and sky brightness provides enough glare to prevent the retina from adapting to road-level conditions (13, p. 84).

Conditions at the Goldsmith grade crossing, particularly in regard to the southbound approach, can be exactly as described above. The area is flat and open, the highway is level and a driver looking ahead at the

horizon sees the sky "coming down to the road." There are times when the sky presents a very bright background. At road level, there is a heavy tree line to the west parallel to the track and coming almost up to it. This tree line presents a dark background. To the east there is also a dark background, although not as pronounced. Many of the trains that use the crossing are black and tend to blend into the dark background.

Photographs were taken of a train against the background to the west on a bright, summer afternoon with a 35 mm electric eye camera. Two views are shown in Figures 32 and 33. These pictures were taken under identical conditions 5-10 seconds apart. It was a hot, bright summer day with cumulus clouds (which can be seen in the figures) casting intermittent shadows over the various areas. The sun was just "breaking out" of cloud cover at the time the pictures were taken.

The writer had an experience in regard to observation of a train against this same background on a similar day that is noteworthy in emphasizing the effect of this background and verifying that the camera does not exaggerate its affect. A short train (8-10 all black cars) was approaching from the west. The writer was looking down the highway to the north into a bright horizon and did not realize a train was approaching until it was in about the same location as the train in Figures 32 and 33. The writer turned quickly upon hearing a train whistle but for a full 3-5 seconds could not see the train although it could be heard. The eyes finally made the proper adjustment and it "became visible."

The affects of age would worsen the above condition as most visual functions deteriorate markedly in older age. Of particular importance are acuity, sensitivity to glare, and vision under low levels of illumination (13, p. 85). Sanders (3, p. 3-28) gives some examples of the effect of age on several aspects of vision, as follows: 1) by age 60 visual acuity drops about 20 percent, 2) capability for dark adaptation is sharply reduced, requiring about double the illumination for every 13 years of age, 3) ability to see against glare is reduced with age to the extent that it takes 50 to 70 times increased brightness for a 75-85 year old to see against brightness as compared to a 15-year-old.

FIGURE 32. FRONT OF TRAIN AGAINST DARK BACKGROUND IMMEDIATELY WEST OF THE GOLDSMITH GRADE CROSSING

FIGURE 33. MID-SECTION OF SAME TRAIN SHOWING CONTRAST OF WHITE TANK CAR AGAINST SAME BACKGROUND

It is, then, an obvious conclusion that the danger potential of a dark train against a dark background is greatly increased to an older driver. It is also probable that the visibility of the before, dim flashers, did not have great impact in the daytime with a background of bright sky, particularly to drivers of advanced age. A copy of a letter written by a woman who lived near the crossing, complaining to the N & W Railroad, was reviewed. She noted that the old signals, "were the dimmest I have ever seen."

Accident Analysis

The accident record was previously presented in Tables 7 and 8. The summary shows that in the 15-year period from January 1, 1957 through July 1, 1972, there were 38 accidents, 8 of which were fatal resulting in 13 deaths. The majority of accidents occurred during daylight hours in good weather and with dry pavement. Twenty-two of the 38 involved southbound traffic.

Considering only the train involved accidents, 12 of the 38 (see Table 8) have occurred since March, 1965. The first three of these (fatal accidents, all in 1965) involved northbound cars and eastbound trains. This combination involves restricted sight distance. The eastbound train is within 200 feet of the highway before it can be seen by a driver who is about the same distance from the tracks. Why the drivers ignored or did not see the signals may be difficult to understand but it is probable that the signals did not have sufficient impact to warn the drivers adequately of an approaching train.

All nine vehicles involved since 1966 were southbound, where apparent sight distances and opportunity to see a train from either direction is excellent. Considering only those that occurred in clear weather during daylight hours (6 of the 9) the pertinent facts are summarized in Table 36.

TABLE 36. SUMMARY OF ACCIDENTS OCCURRING SINCE 1966 DURING DAYLIGHT AND CLEAR WEATHER

Date	Train Speed	Train Direction	Vehicle Speed	Age	Killed	Injured
12/24/66	40	EB	60	76	0	1
12/25/66	40	WB	55	55	0	1
3/ 6 /70	53	EB	75	47	0	1
9/ 5 /71	54	EB	60	73	4	0
10/13/71	50	WB	?	80	1	0
10/29/71	51	WB	65	71	2	0
MEAN	48		63	67		

Except in the case of the 3/6/70 accident (driver hit train) speeds were not excessive. The most obvious factor that stands out is "age." Note that the mean driver age is 67. All three drivers involved in seven fatalities occurring since 1966 were over 70. This is in accord with the only significant finding of Sanders' (3) search for a high risk subgroup, those with demonstrated degradation with age.

Visual acuity deteriorates rapidly with age. The deterioration is significant past the age of 40. Even though background conditions during September and October may not have been as severe as they can be during the mid-summer months with full foliage on the trees, one cannot ignore the combination of advanced age, dark or dull background, dark trains, relatively dim signals and driver expectancy. In regard to the last point there are two adverse possibilities. First, a driver unfamiliar with the area traveling several miles on a freeway-type facility might not expect a grade crossing, i.e., he is surprised by the presence of a train. Secondly, a driver familiar with the general area has probably crossed this low volume crossing many times without seeing any sign of a train.

In either case, the newer, brighter signals, the extra signals over the roadway, the gate arms and the strobe lights on these arms tend to reduce or eliminate this aspect of the danger. The only other

visual improvement that could give added insurance visibility of the white railcar in Figure 33 is obvious.

The Dilemma Zone

Except for free-flow vehicles almost all of the speed data were taken of cars entering the system after the signal system was activated. However, there were a few cases when it was apparent that no car was going to enter the system soon after the system was activated that a vehicle within the system at activation was followed through the system. It is emphasized that these data are not to be considered a representative sample and conclusive inferences would not be appropriate; however, a study of these vehicles emphasizes the unpredictability of driver actions at grade crossings. The data are summarized in Tables 37 and 38.

There was one unusual chance occurrence. With the telephoto lens, only one car at a time could be picked up and panned through the system. By chance, two cars came into the system together, one in each lane, and stayed together through the first five traps such that it was possible to follow both. At about the fifth trap an approaching train activated the signals. Both vehicles initially slowed, but one decided to continue under the descending gates while the other continued decelerating to a stop. This contrasting driver strategy can be seen in a plot of the two approach profiles shown in Figure 34.

From the vantage point of the writer, the driver that chose not to stop appeared to have been close to hitting the descending gates; therefore, it could be classified as a bad or reckless decision. This situation emphasizes another advantage of automatic gates. The driver in this case "got away" with his bad judgment.

It was noted while taking data in the field that cars that were in the seventh or eighth trap (within 200 to 300 feet) when the signals were activated almost always went through the crossing. Considering that a vehicle could travel 264 feet in three seconds even at the moderate speed of 60 mph (88 ft/sec) this would be the proper action, preferrable to trying to stop.

TABLE 37. CARS THAT WERE IN TRAPS WHEN SIGNALS WERE ACTIVATED AND STOPPED

Trap #1 Speed	Trap #2 Speed	Trap #3 Speed	Trap #4 Speed	Trap #5 Speed	Trap #6 Speed	Trap #7 Speed	Trap #8 Speed	MAXIMUM DECEL-ERATION
58.1	56.8	56.3	56.3	56.3	****[3] 56.3	43.9	0.0	13.3
69.2	69.2	69.2	69.2	69.2	**** 69.2	47.3	0.0	17.5
64.2[4]	64.2	64.2	64.2	**** 64.2	56.2	47.3	0.0	15.5

Notes:

1. All values of speed = miles/hour
2. All values of deceleration = ft/sec/sec
3. **** indicates trap entering (approx.) when signal activated
4. Plotted in Figure 57

TABLE 38. CARS THAT WERE IN TRAPS WHEN SIGNALS WERE ACTIVATED AND DID NOT STOP

Trap #1 Speed	Trap #2 Speed	Trap #3 Speed	Trap #4 Speed	Trap #5 Speed	Trap #6 Speed	Trap #7 Speed	Trap #8 Speed	MAXIMUM DECEL-ERATION
56.2	56.2	60.0	60.0	60.0	60.0	60.0	****[3] 56.2	3.0
56.2	56.2	60.0	60.0	60.0	60.0	60.0	**** 56.2	3.0
64.2	64.2	64.2	66.6	66.6	66.6	69.2	**** 69.2	0.0
69.2	64.2	62.1	62.1	58.1	56.2	56.2	**** 56.2	4.5
72.0	72.0	69.2	69.2	69.2	**** 69.2	56.2	36.0	12.9
64.2	60.0	60.0	60.0	60.0	**** 56.3	42.8	20.0	9.9
60.0	60.0	60.0	60.0	**** 60.0	60.0	60.0	60.0	0.0
64.2[4]	64.2	64.2	64.2	**** 64.2	56.3	58.1	64.3	6.6

Notes:

1. All values of speed = miles/hour
2. All values of deceleration = ft/sec/sec
3. **** Indicates trap entering (approx.) when signal activated
4. Plotted in Figure 57

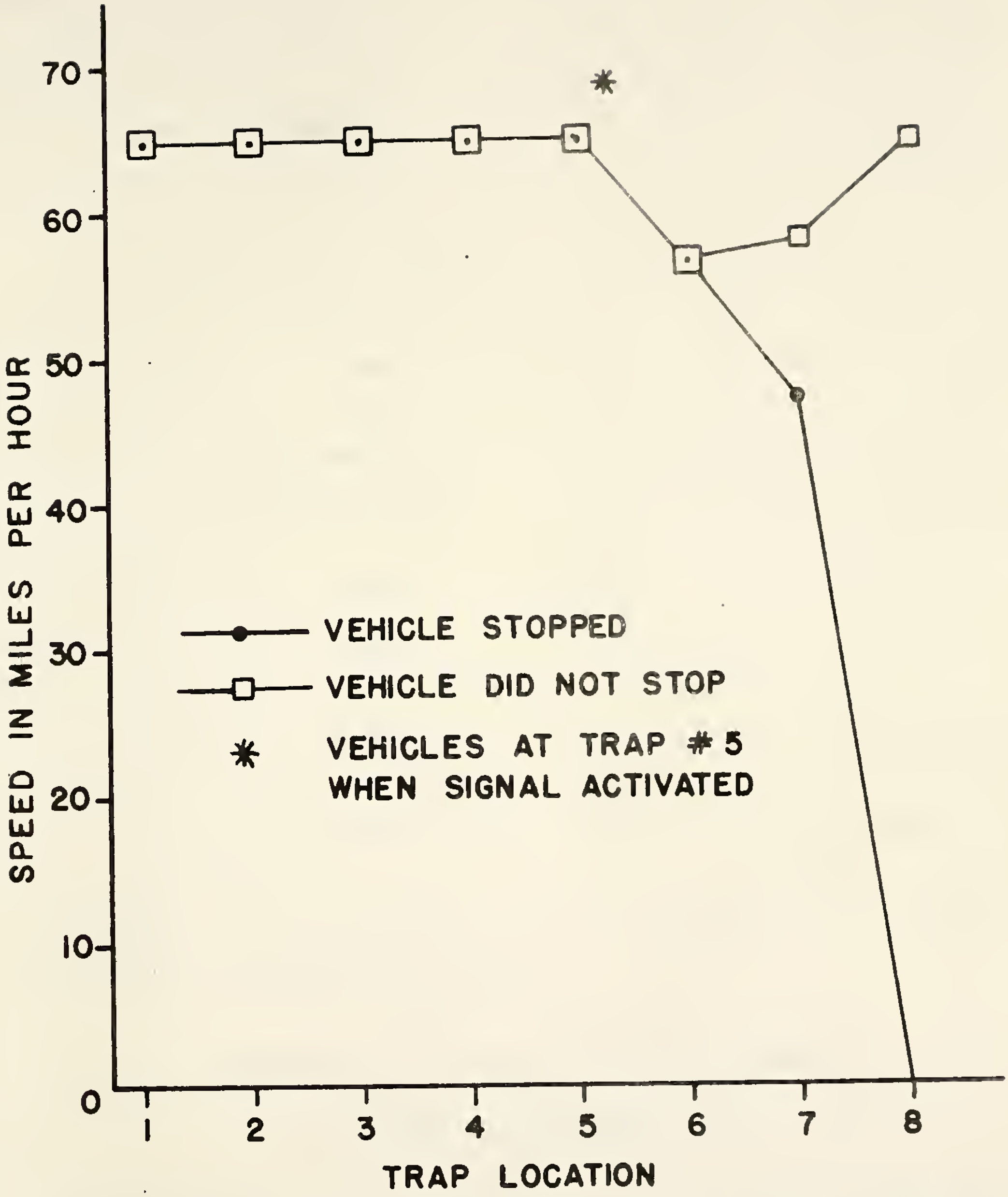

FIGURE 34: TWO VEHICLES APPROACHING CROSSING TOGETHER : ONE STOPPED, ONE WENT THROUGH THE GATES COMING DOWN.

The gates at this crossing start down concurrent with signal activation. This is not in accordance with current practice which recommends a three-second delay. However, even without the delay it appeared to take 6 to 7 seconds for the gates to be down enough to be in danger of being hit by a car. In this length of time a 60 mph vehicle could possibly "make it" from 500 to 600 feet. One vehicle, as can be noted in Table 38, "proved" this point by maintaining a constant speed of 60 mph from Trap 5 (where the signals were activated) through the system and "just" making it under the gates.

It was the observer's opinion (or conjecture), based on the fact that the driver did not speed up in view of the signal activation, that he expected some delay in gate descent. The recommended three second delay appears to be warranted and should be in effect at this crossing.

Under the present operating conditions (no delay) the greatest conflict with the descending gates most likely occurs to a driver who is in the region of Trap 4 or 5 when the signals are activated, who initially brakes, and then changes his mind and tries to go on through. If a driver is going to beat the gates from this distance he had better make the decision quickly and not slow down while he thinks about it.

It did appear to the observer that many drivers who were no farther into the system than Trap 6 when the signals were activated tended to stop. As can be seen by the examples in Table 37, such drivers can stop without excessively high rates of deceleration. The highest of the three examples is 17.5 ft/sec/sec which is classified as "very uncomfortable" but not considered "emergency."

Evaluation of the Data Collection System

Limitations and Recommendations

Although the data collection system was effective in determining speed profiles and decelerations, several limitations became apparent during the study. As the project was initially conceived it was intended to collect data at night as well as during the day. Attempts were made with illuminated markers and sensitive film to pick up these

markers and the headlights of passing vehicles. This proved to be unacceptable because cars not equipped with front and rear "running lights" did not show up in the films after passing of the mid-point of the approach.

One solution to the above problem is suggested. If the camera had been set-up closer to the track, it can be visualized (refer to Figure 8) that the headlights of all vehicles would have been visible throughout all of the traps. This location would also have expedited set-up effort by cutting down the carrying distance of camera equipment through the fields every time one wished to set up and take data.

A location closer to the tracks could have other advantages. It would be easier to spot approaching trains because of looking directly along the tracks, thus there would be less danger of not being ready when a train approached. Also, this set-up location might require less sight distance than that required for the set-up shown in Figure 8, i.e., less of an "open" quadrant in terms of area. This can be easily visualized by using Figure 8 and visualizing the camera set up near the tracks and perhaps closer to the road. Obviously, sight distance required to use a camera is a drawback because to obtain data on an approach it is necessary to have clear sight distance for the camera in at least a large portion of the quadrant of that approach no matter where the camera is positioned.

For this project markers were essentially put in line along the highway right-of-way near the fence line because it was convenient to do so. It is only required that they be put somewhere along the line of sight between the camera and the end points of the traps. However, to minimize error it is desirable to place the markers as distant from the camera as possible.

It is also strongly suggested that, if at all possible, some shelter from the elements be built. This is essential if it is desired to collect data during all seasons of the year and/or during all types of weather conditions. This would not only protect the equipment but would make conditions more tolerable for an observer in all weather. The equipment is durable enough but rain on the lens blurs the pictures;

therefore, it must be protected in inclement weather. An observer must spend numerous hours physically idle when trains are few and this can be very uncomfortable in bad and/or cold weather.

One other problem at this particular site was the problem of growing crops in the fields cutting off the sight distance late in the summer. It is suggested therefore that the camera position be such that the camera can be elevated above these crops. This problem at this particular site was solved by using a step ladder over the point and holding the camera with a special shoulder harness from the top of the step ladder. This solution was considered effective, however, a permanently constructed elevated platform probably would have been better and safer - but more costly.

Figure 35 shows the "normal" camera set-up. It is over the point that a transit was set when laying out the lines of sight to the measured trap-limits. The note pad in the figure illustrates the method used to take and record notes on the film, i.e., appropriate notes were written and then photographed with the camera.

Figure 36 shows the set up that had to be used after the beans in the southeast quadrant grew to the point that the targets and vehicles could not be seen over them. The portable tripod and shoulder harness are standard equipment used by newsmen, etc. The greatest drawback was "balancing" on the ladder. After some "learning" experience, it was possible to keep the camera reasonably steady, but a platform would have been better.

Since it was necessary on this project to use a 120 mm telephoto lens and "pan" with the camera to follow a car through the sequence of traps, the distance from the road could have been increased to 1000 ft. or more with no additional disadvantage. Taking advantage of this greater distance may allow a more convenient set up location, e.g., a field access road may be available. With larger markers, one could take advantage of even greater camera range. However, one must consider the possibility that large markers could possibly be too conspicuous and, therefore, have an effect on driver performance that could bias the results.

FIGURE 35. CAMERA SET-UP, READY FOR DATA COLLECTION UNDER NORMAL CONDITIONS

FIGURE 36. CAMERA SET-UP USED TO SIGHT OVER BEANS THAT OBSCURED THE LINE-OF-SIGHT LATE IN THE SUMMER

One reason for the selection of the particular camera that was used was simply that it was a good camera and it was available. However, if one were to purchase a camera, an 8 mm could possibly be just as effective and certainly more economical. However, a powerful zoom lens is a necessity to obtain adequate distance off the roat to permit accurate analysis of the data.

The following additional suggestions resulted from experiences in this study:

1. Watch the marker background. It was observed that no matter how clear the path of sight to the white marker, when it was against the horizon its image on film was not sharp, and sometimes difficult to see at all, particularly when the sun was at a low angle behind the marker.

2. Data reduction was more troublesome on film taken in the first half of the morning looking east, and the late afternoon looking west. This relationship to the sun should be considered when a camera set-up point is chosen. If it is possible to get a dark background behind the markers, this problem should not arise unless the sunlight is directly into the lens.

3. While standing in the field, sighting through the camera lens, if the markers are partially obscured to the eye, data reduction from the film will probably be troublesome. The NW quadrant set-up was in the middle of a cornfield and near the end of the summer only the tips of some markers could be seen but they appeared to be very clear when viewed by eye in the field. However, after the film was developed and projected, it was extremely troublesome finding some of them.

4. It is recommended that the data collection procedure be considered a two-man operation. The procedure requires that one simultaneously keep track of: a) approaching trains, b) approaching vehicles, c) focusing and aiming the camera, d) the start of signal operation, e) picking up the first vehicle into the system, and f) film speed while "panning" a vehicle through all the traps. Considering these five aspects of the procedure concurrently is a difficult task conducive to periodic error.

5. Where brush has to be cleared for a clear line of sight to a marker, make sure that more than a minimum amount of clearing is done, in other words, an area that encompasses more than just the trap itself. It is recommended that lines of sight of at least three or four car lengths (or more) be clear prior to the first marker of the system to allow for the reaction time necessary to "pick up" a vehicle through the lens and follow it through the system.

The system as designed for the project on U. S. 31 near Goldsmith can be considered a permanent installation, i.e., the trap markers are firmly imbedded along the edge of the highway right-of-way and can be used repeatedly year after year. For analysis of data at several grade crossings a portable system could easily be developed.

Lastly, in addition to being quick, inexpensive and effective for data collection the camera method has one additiona, inherent advantage. Before, or while taking data, the observer can photograph the surroundings and get a permanent record of the physical features of the area. This, plus photographed notes, is extremely helpful during the data reduction and data classification and/or grouping process. The complete record of the conditions during data collection is right there with the data. Conditions such as weather are obvious.

The final, general conclusions that can be drawn from the use of the photographic data technique on this project are:

1. It is effective.
2. It is inexpensive and can be quickly and easily implemented.
3. It provides a superior permanent record.

CHAPTER 6: ANALYSIS OF FHWA DATA BASE

Introduction

In an attempt to fill the void in knowledge of driver reaction to grade crossings, FHWA sponsored a research project to record and analyze driver reaction in the vicinity of grade crossings. The primary anticipated use of the data was to have been to determine value of vehicle delay for the time delay portion of economic models or warrants. The subsequent final report by Sanders (20) also stated that other valuable results could be obtained by further analysis of the data, such as driver reaction during periods of transition from day to night, dry pavement to wet pavement, etc. Thus, the data were stored by FHWA and were available on magnetic tape to anyone with an interest.

As stated by Sanders (20, p. 25-27):

> The data collected at each site was generally divided into several files by the observers who operated the traffic evaluator. A file mark was written on the tape whenever any occurrence which might tend to influence the quality of the data was noted. Examples include equipment malfunction, the start of rain or snow, the presence of hitchhikers, vehicles stopping for repairs, illumination transitions at sunrise and sunset, etc.
>
> As might be expected, even though the data collection period began in clear weather, some adverse conditions were experienced. The data used in this study was restricted to dry pavement and clear visibility. A considerable volume of vehicles were recorded during periods of rain and snow.
>
> The data which was collected under conditions not comparable among all sites was not analyzed. Analysis of behavior during specific transition periods such as from day to night or dry pavement to snow could produce valuable result, therefore this data has been retained and is available for further study.

The tapes were obtained and included various attachments explaining the nature of the data and its orientation on the tape, including sample output from the FHWA computer. The material pertaining to the data is reproduced in Appendix B; namely, Table B1) Attachment A, an index to site specific information, Table B2) Explanation of Annotated Listings, and Table B3) Attachment B, a speed profile key into which all vehicles were categorized and coded.

The "index" refers to one of 78 separate files of reconstructed vehicles that broke the data down by sites, site directions and any "data-influencing" condition. Each of the 26 sites was broken down by direction so that there were 52 site directions. In other words, each site (1-26) had a minimum of two files, one for each direction. In addition, any one of the 52 site directions may have been further broken down by occurrences that could affect the data. This meant that any given site could have had any number of indices. It can be noted from Appendix B, Table B5 that the maximum is six. The summation of all indices, two to six, for the 26 sites, added up to the 78 indices or 78 separate tape files listed in Table B1 (Appendix B). The data were contained on tapes designated RAILBU containing indexes 1 through 39 and RAILBW containing indexes 40 through 78.

The data base was acquired with two initial goals in mind. The first was to compare it with the U. S. 31 data. The second was to further analyze the FHWA data for whatever results could be obtained to support conclusions of the U. S. 31 data.

Significant Problems

The index numbers were the primary key to assessing a particular site, or more specifically, a particular site occurrence. One of the first obvious problems with the data set was absence of index numbers.

Each line of data was for one of five traps. Since there were 224 characters per line it had to be printed out as two lines of output. Thus for every vehicle that passed through the five traps that comprised the system, there were ten lines of output. The complete data set contained data on 20,198 vehicles which meant 100,990 lines of data

(201,980 lines of computer output). The great bulk of data was a problem.

The Index contained the number of vehicles per file (location index); but numerous attempts to separate the files properly using these numbers proved to be unsuccessful. As a last resort, the entire data set was printed out and studied line by line to find file end-points primarily by breaks in the time sequences, using the number of vehicles listed on the index as a guide.

In the manner described above, it was finally determined that on the first tape, RAILBU, the data at the beginning of the tape did not correspond to the Index. It was obvious that there was no correlation between the data on this portion of the tape and the first eleven site locations as listed on the Index. All the remaining index locations, 12 through 39, as listed in the Index corresponded to breaks in the data which also related to the listed vehicle counts.

On the second tape, RAILBW, this problem did not exist. However, it was found that a few of the vehicle counts were wrong which had been the cause of not being able to find all correct end points of the various files by line counts.

There was one additional inconvenience with the data. The various file indices for a particular site were put on tape in apparently no particular order. For example if one wished to put all the data together for site 30-28-1, the lane two data index was 21 whereas the lane one data index was 71 and those were on two different tapes. Although not impossible, just to "collect" all data for one site even with the computer was a nuisance.

Other sites were split into as many as six indices such as shown in Table 39.

The particular site in Table 39 was chosen to illustrate one other point. Note that the "comments" column could possibly lead to some valuable information in regard to drivers' reactions to grade crossings. For example, does the speed profile change from afternoon to early evening, and how much change occurs during the period of rain. It was expected that similar transition periods at other locations would

TABLE 39. ILLUSTRATION OF THE BREAKDOWN OF SITE INDICES

Reference	Site	Index	Lane	Time	Comments
15	16-42	16	2	1625 1750	Afternoon to Sunset
		17	2	1740 1942	Sunset to Rain
		18	1	1740 1940	Sunset to Rain
		19	2	1943 2133	Rain
		33	1	1625 1750	Afternoon to Sunset
		73	1	1943 2134	Rain

provide data to study changes in driver reaction due to changes in site conditions. However, this site was the only one with such meaningful comments in regard to the reason for the breaks in the data.

Many other site locations have several separate indices indicating that some change in the weather (or similar significant occurrence) <u>may</u> have occurred, but there were no comments recorded on the Index, nor were there anh in the report, to confirm what particular changes had taken place. Except for differences due to different time periods, and as noted at the one site, the value of the data in this regard appears to be severely limited.

Several attempts were made to obtain more information on the way the data was put on the tapes as well as an attempt to obtain additional data on the conditions which were relevant to the division into location indices at various sites. This was done through FHWA personnel who wanted to be helpful, but no additional information could be found.

<u>Revised, Sampled Data Set</u>

Although it was apparent that the data set would probably not yield any great amount of information or reliable results, it was

decided to continue some analysis for possible meaningful comparisons with the U. S. 31 results.

After determining how to locate the end points of each of the 78 location indices, a program was written to reduce the data to a more manageable set.

The original data set was reduced to about 18,000 lines, each containing the speed of a vehicle at the five traps. There were, however, large variations in the numbers of vehicles recorded at each site. For example, at site 100-VD-1 from 0900 to 1500, data were taken on 2490 vehicles on the East side approach but on the West side approach, during the same time period, only 175 vehicles were recorded. Other index locations varied in quantity of data from 1 vehicle to 1266. Since there was no indication that this variation in numbers was planned or had anything to do with expected variance of the data, it was decided to sample the larger subsets to further reduce the data.

The SPSS package available on the Purdue computer system contains sampling program. A SAMPLE command provides a means for taking a random sample of any size from any data set or file for further processing. The sampled set can also be saved.

All vehicles other than cars that did not stop were separated and set aside for possible additional analysis. Also, all vehicles that approached while the signals were activated or with a train approaching were also stored as a separate data file. Location indices of the remaining portion of the data were sampled. If the number of vehicles in any particular location index was greater than 100 cars, a sample of about 100 cars was obtained. If the number of vehicles was less than 100, all of them were included. This reordered, sampled set further reduced the data to a more manageable level.

One other set of parameters had to be added to the data set. In order that deceleration rates could be calculated, distances between points where each of the five speeds were recorded had to be known. These distances were not constant as was the case at the Indiana, U. S. 31 site. It appeared that the tape switches were put down at approximate distances, perhaps where convenient, and then measured. The first

three traps were placed on each approach and two additional traps were beyond the crossing.

The distances from the first "trap" to the track varied from 1376 feet to 376 feet, with most being between 1000 feet and 500 feet. The second "trap" locations were mostly between 200 feet and 100 feet of the crossing. The "trap" closest to the tracks was all on the order of 0 feet to 15 feet from the crossing.

Unusable Locations

The first 11 location indices were not available from the data set. Obviously, this affected any sight whose data set included on of these files. There were six locations affected partially or totally (Table B5 in Appendix B). It can also be noted in this table that four of the location indices (59, 44, 65, 57) had data on a total of six or less vehicles, from which it is obvious that no meaningful results could be obtained.

Three other sites only reported speed profiles on one approach, sites 2-42, 30-28-1 and 100-VD-1 (ref. 20, p. A-7, A-71 and A-9). Speed profile of the "other" approach was labeled "NOT AVAILABLE" in each case. Also, not available for these approaches were distances to the speed location points.

Site-Specific Information

Geometry. The only data obtainable in regard to site geometry was from sketches in Sander's report (ref. 20, Appendix A).

Roughness. A subjective roughness measure was determined for each location to account for some of the difference in speed variation between crossings. The hypothesis was (20, p. 29):

> ... the reduction in speed from the desired speed measured at a large distance before the crossing to the speed at the crossing would be the greatest for the most rough crossings, and lowest for the most smooth.

It was determined that this hypothesis was true. This can be seen in Figure 37. Therefore, any comparisons of different sites had to be

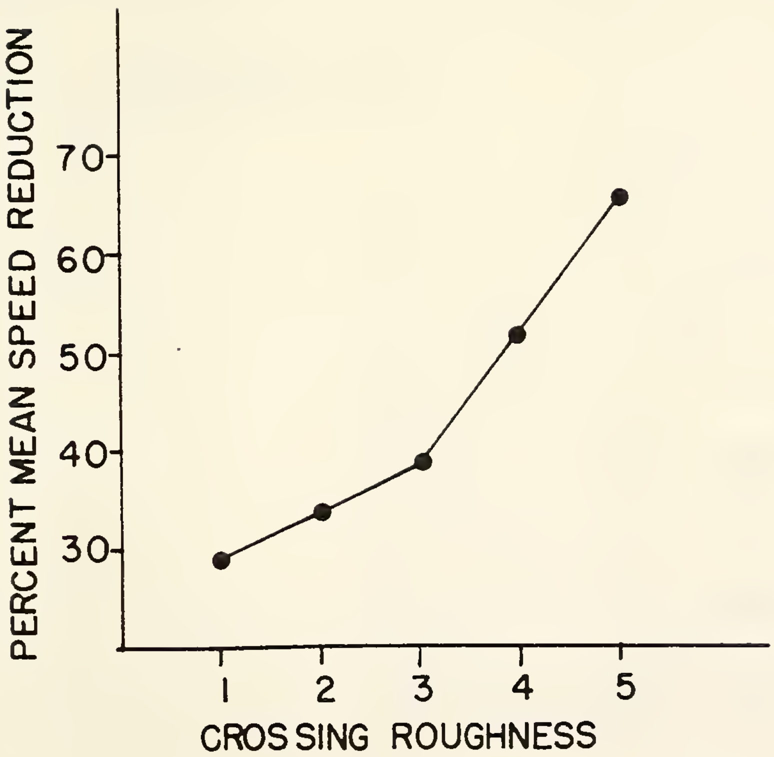

FIGURE 37: MEAN PERCENT SPEED REDUCTION FROM DESIRED SPEED TO CROSSING SPEED BY ROUGHNESS CATEGORY. (SOURCE: REF. 20, P. 30)

between crossings of equal roughness or the roughness had to be considered as a variable.

Data Analysis

Much of the data were for cars that did not stop. In the terminology of the analysis of Indiana U. S. 31 data, most of these would be analogous to free-flow vehicles.

One sub-set of data was all vehicles that were in the system with either a train present and/or signals operating. The fifth column of the revised data set contained the vehicle type code. The key is presented in Table 40.

TABLE 40. SPEED PROFILE KEY

Type	Explanation
1	Passenger car which did not stop
2	2-axle truck which did not stop
3	Bus which did not stop
5[1]	Truck combine which did not stop and not required to stop
6	Passenger car which stopped
7	2-axle truck which stopped
8	Bus which stopped
9	Truck combine which stopped and required to stop
10	Truck combine which stopped and not required to stop

Note:

1. No type "4" defined or used
2. Explanations from reference 20

The data set consisted primarily of type 1 vehicles, approximately 16,000. All vehicles other than type 1 were separated into their own data set of 1708 vehicles.

An obvious objective was to acquire information on the nine approach profiles (Table 40) in regard to their similarities and differences.

It was also felt that pairwise comparisons, such as, buses that did not stop vs. buses that stopped, trucks and/or truck combines that did not stop vs. trucks and/or truck combines that did stop, could give valuable insight into the point on the approach that the decision or action to stop started. For those drivers of vehicles required to stop at grade crossings, the point of beginning deceleration could be an indicator of the impact of a particular warning system or geometry or combination of both. For example, truck drivers, knowing that they are going to stop at a grade crossing, should begin this maneuver at some "average," safe distance from the crossing. At any given crossing where the action was started significantly closer to the crossing than the average, it might be concluded that the warning system was not having the desired impact on the driver. This would be particularly true if all drivers were not familiar with the area and did not know when a grade crossing was ahead.

The data set was broken down by type. For each type the average speed of each of the five traps was calculated. This "mean" profile for each category was plotted. The results are shown in Figure 38.

It was found that there was a complete absence of type 9, "truck combine which stopped and required to stop." Also, type 10, "truck combine which stopped and not required to stop," contained only two entries. Sanders (20, p. 32) reported obtaining data on 339 buses of which 202 stopped. The data set obtained from FHWA contained 190 buses of which 33 stopped.

From the diagram, Figure 38, it can be seen that some of the categories that reportedly stopped, type 6 through type 10 (dotted lines), were going faster at the crossing than those that did not (solid lines). The data were carefully examined by studying the

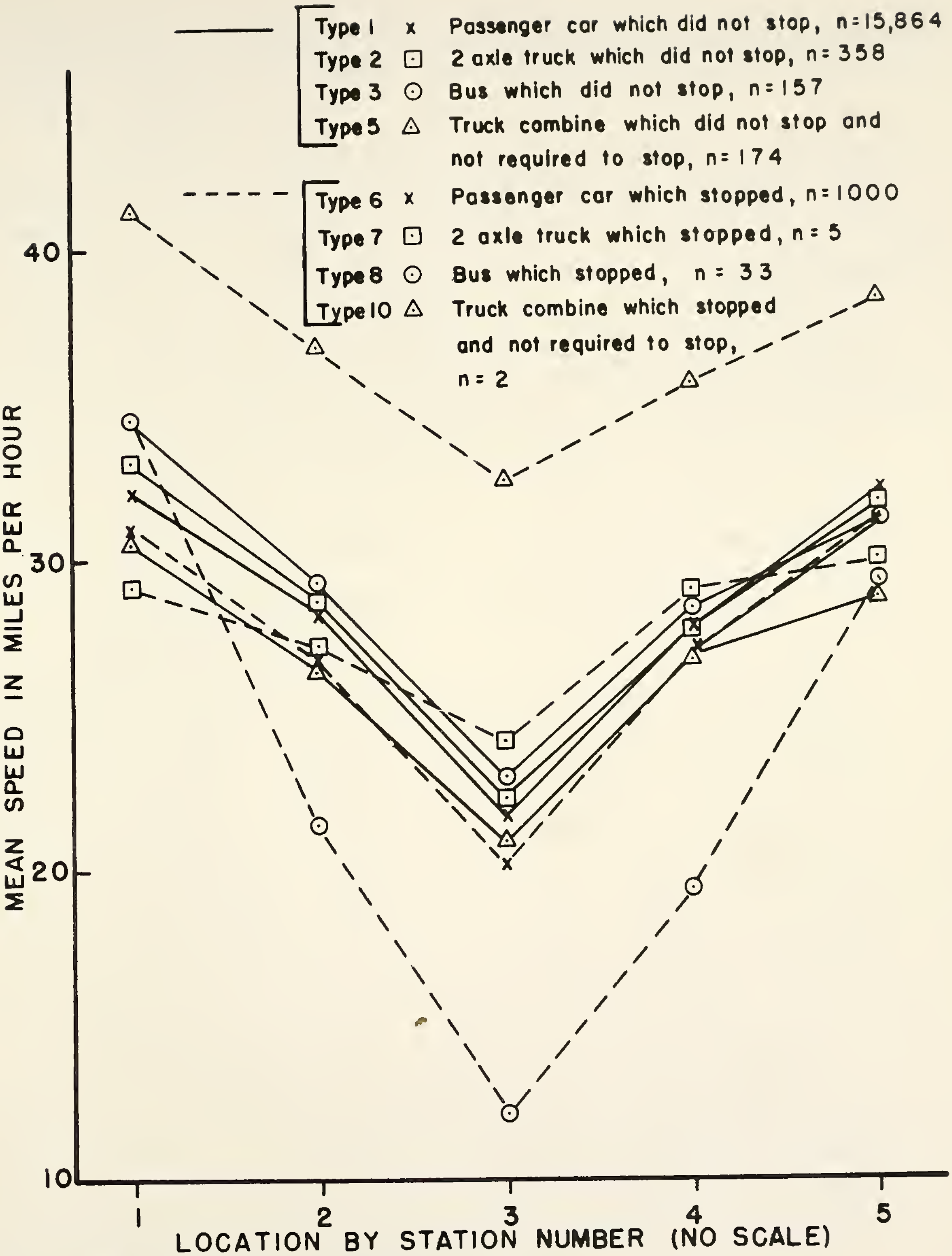

FIGURE 38 SPEED PROFILES OF ALL CLASSES OF VEHICLES CONTAINED IN THE FHWA DATA BASE.

complete set until the author was convinced that these mean speeds shown in the figure represent the data and are not the result of errors in the computer program.

In addition, the mean speeds of type 1 vehicles were replotted in Figure 39 to approximately the same scale as those in Sanders' (20) report (refer to Figures 3 and 4 in Chapter 2). The plot of these mean speeds, both in miles per hour and as a percentage of entering speeds, show that the results are generally consistent with the plots in Sanders' (20) report. This implies the same data base, although the latter had more restrictions on the data set which comprised the means of the plot, specifically the following three:

1. Data were taken only from grade crossings with roughness index <2.5
2. Data were taken only from grade crossings on two lane roads, and
3. The data were a different sample of the total set at each location.

From the above analysis of the data set, there is no reason to doubt the validity of the data for type 1 vehicles (passenger cars) that did not stop. It appears, however, that the data for the other types of vehicles, especially those that stopped, as recorded on the available tapes, are unrelaible. Note that three of the four mean speeds from supposedly "stopped" categories are greater than 20 mph, and that two of them are greater than the type 1 group classified as passenger cars which did not stop. It should be noted that Sanders (20) primarily utilized the type 1 vehicles which did not stop for his report and there is, therefore, no contention with his results.

It was decided that further analysis of the data would not be beneficial. No matter what significant results were apparent by any analytical means at or between any of the grade crossings or groups, there was no assurance as to what the results were due to. Besides, whatever discrepancies there may have been in the data, there was no first hand knowledge of site-conditions.

The data for cars that did not stop appeared to be valid. Attempts were made to compare results to the U. S. 31 free-flow data. However,

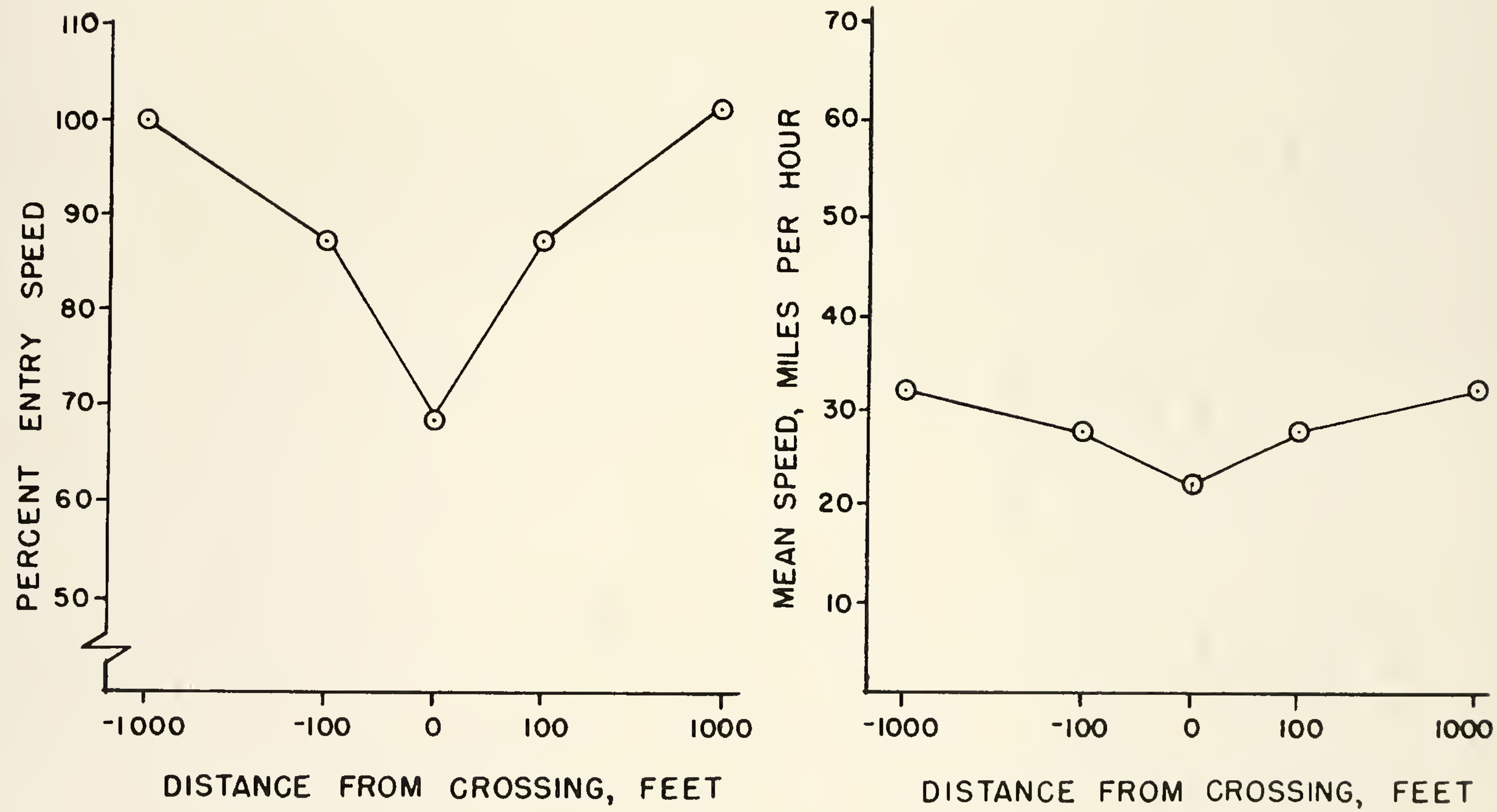

FIGURE 39 SPEED PROFILES FOR MEAN SPEED OF ALL TYPE I VEHICLES CONTAINED IN THE FHWA DATA BASE

at the U. S. 31 crossing there were eight traps on the approaches at fixed distances. The crossings of the FHWA data had only three, at varying distances.

One attempt was made to "convert" the FHWA data to comparable speeds by assuming constant deceleration between points and interpolating and/or extrapolating to calculate eight equivalent speeds on each approach. The calculated results were such that the values appeared to be unreliable, e.g., extrapolations to speeds in excess of 100 mph in some cases or negative speeds in other cases. In addition, there was no way to rate the roughness factor at the Goldsmith grade crossing such that it would be consistent with the subjective ratings of the crossings of the FHWA sponsored study.

CHAPTER 7: SUMMARY AND CONCLUSIONS

Summary

This summary is directed toward tying the report together but is limited to specific points directly associated with the conclusions that follow.

There is a definite need for reporting and coordinating all transportation related accidents. This is particularly true at highway-railway grade crossings. The FHWA Office of Research is attempting to validate accident prediction models for urban/rural, active/passive categories. However, there are only a relatively few states who have suitable data. The national grade crossing inventory is a step forward in this regard.

There are major weaknesses with predictive models based on accident experience--in addition to the faults inherent in the data base. Research indicates that current regression equations explain only a small percentage of the accident experience. Typically such equations include volumes and physical characteristics of the crossing and do not include characteristics of the driver. Predictive equations have limited usefulness and it is reasonable to hypothesize that a certain level of accident experience is a confounding of driver error and chance which defies quantitative analysis.

An extension of accident prediction equations is the attempt to include some sort of economic analysis; i.e., make improved protection cost-effective. One can conclude from the literature that there are many concepts but no real concensus in regard to what constitutes a completely valid and/or proper economic analysis. The factors which are included range from aggregated driver and vehicle delay costs to placing a cost on lives. Both are debatable from the standpoint of what values should be used. Most past economic studies appear similar to the benefit-cost studies given heavy usage in past years to justify

public works improvements. In the case of grade crossings the effectiveness portion of the cost-effectiveness approach is difficult to evaluate because there is no proven way to measure it short of long-term accident experience.

It is now generally accepted that flashing lights and gates reduce materially the number of accidents that occur at railroad crossings. This is particularly true of automatic gates which are generally accepted as being superior to flashing lights alone. However, there is not total agreement of objective criteria on which to base a set of warrants which would optimize their use, make them "cost-effective" or at least insure that they are used in locations where they will do the most good relative to meaningful priority ratings.

Drivers desire improved communication in dangerous situations; particularly at grade crossings which they consider to be very dangerous. They need some active warning with a high degree of reliability. When drivers are alerted unnecessarily they tend to disregard the warning. Rural, high-speed locations of relatively isolated grade crossings need warning of train approach with greater impact on the driver.

Driver Reaction at a High-Speed Rural Grade Crossing

This research concerned driver reaction to two different signal systems at a high-speed, high-accident, rural grade crossing. Essentially it is a before and after analysis, as the protection was upgraded from old, standard flashers to a modern automatic gate installation activated by a Marquardt speed predictor, as well as an evaluation of possible measures of crossing warning effectiveness. An Interim Report (29) reported an independent analysis of the before data. The after data were subsequently analyzed with the raw before data for the final analysis presented herein.

One objective of the research was to evaluate parameters that measure effectiveness, such as, approach speed and deceleration rate. Speeds at eight traps on each approach and deceleration rates between each trap were calculated. For several categories of before and after vehicles numerous comparisons were made.

The information was analyzed in the context of the physical conditions of the site and their relation to the human factors literature. Particular attention was given to conditions affecting visual acuity and train conspicuity.

Finally, some atypical data relating to variability of driver reaction when near the crossing and confronted with gate activation and the immediate decision of stopping or not stopping were analyzed.

Data Collection System

The Goldsmith study was undertaken quickly on a very limited budget. An inexpensive, easily implemented data collection system was developed. The data collection system was studied during the course of the project to evaluate its shortcomings as well as recommend procedures to enhance the operation. Basically, markers were placed along the line of sight of a 16 mm variable speed camera and 55-foot speed traps were marked along the centerline of the highway. By running the camera at a constant speed, a vehicle was photographed from one marker to the next and the vehicle's speed was calculated from the frame count after the film was developed.

FHWA Data Base

FHWA sponsored a project to record and analyze driver reaction in the vicinity of crossings. A resulting data base was developed by the contractor. Originally, the data were used for determining the value of vehicle delay for the time-delay portion of economic models and warrants.

A large portion of the data was not analyzed and was available for further analysis (20). It was anticipated that an analysis of these data would supplement the analysis of the Goldsmith data.

Conclusions

The following are the conclusions of this study:

General

1. To compare parameters associated with driver reaction and changes in reaction due to improvements or changing conditions at actively protected grade crossings, the categories, "free-flow," "first-unobstructed," "first obstructed," and "following" proved to be adequate and should be given consideration as standard terminology.

2. The analysis of the Goldsmith crossing data, including mean speeds, mean deceleration rates, mean speeds of above-pace drivers, individual speeds of fastest drivers and highest deceleration rates showed that no driver in the before and after samples approached in a manner that resulted in an accident or a near miss implying:

a. Grade crossing accidents involve singularly inattentative drivers.

b. Mean values of speed and deceleration are weak parameters for evaluating hazard at a grade crossing or the effectiveness of grade crossing warning improvements, because almost all drivers approach a crossing in a safe manner.

c. There is a need for constant monitoring or long term sampling to "catch" the occasional erratic drivers and evaluate the characteristics of such drivers.

3. Examination of the individual fastest drivers showed an absence of any definable approach trends before and after.

4. Mean approach speeds, although a weak parameter for conclusions regarding warning effectiveness did provide information on driver approach characteristics:

a. They approached slower when the amount of stimuli present was greater, such as a train across the track or a gate down.

5. All free-flow plots and several statistical tests showed a consistent lowering of mean approach speeds 1100 feet from the crossing after improvement, implying that drivers were aware of the crossing after improvement farther from the crossing, due to the visibility of the gate arms in the raised position.

6. Although the Goldsmith grade crossing is in a rural area, the two approaches are different in character; namely, the north approach was truly "rural" while the south approach might best fit a "suburban" description because of development on the approach.

a. On the "suburban" approach, northbound traffic did not take further decelerating action, relative to entry speed (at 1100 feet), until around 500 feet from the crossing even when alerted earlier, supporting other research (Sanders, 20).

b. On the "rural" approach, southbound drivers began to decelerate further, relative to entry speed, at about 700 feet from the crossing implying that on this high-speed rural approach drivers reacted earlier than "suburban" drivers when alerted earlier.

7. Analysis of >72 mph vehicles within the approach distance (1100 feet), before and after, showed that there was the same percentage of northbound drivers >72 mph but the percentage of southbound drivers >72 mph decreased from 23.6% before to 13.6% after.

Driver Reaction to Activated Signals

1. The plots of the "first obstructed - after" (by gates) were comparable to the "first obstructed - before" (by train), and in the case of southbound vehicles there was no statistical difference between values at any trap. Thus the gates with strobe lights had the same effect as a train across the road on slowing the average motorist.

2. The approach speeds of following vehicles were more affected by other vehicles than by the signal, before and after, and their approach speed profiles were independent of signal type.

3. Studying individual fastest cars entering the system just after signal activation showed that there was a substantial decrease in the percentages of speeds greater than 65 mph than when the signals were not activated, particularly on the southbound approach. The implication is that the signals, both before and after, had some impact at distances greater than Trap #1 (1162 feet).

5. From personal observation and comments from "visitors" to the site, the most alerting aspect of the new signal system is the strobe lights on the gate arms. The use of strobe lights on gate arms merits further study to measure driver reaction to varying degrees of brightness, flash rate, and distance of impact--both day and night.

6. There were no deceleration rates at the Goldsmith grade crossing that classified as emergency before or after upgrading the protection. There was a reduction in the decelerations above undesirable classifications for the after system but the numbers before as well as after were too few to permit statistical comparison.

Visual Acuity

1. At the Goldsmith grade crossing, dark trains against a dark background on both rail approaches, and particularly to the west, presented a subtle but dangerous sight visibility problem to the southbound driver. A bright sky before the driver on the road approached further reduced the capability of his eyes to adjust to either a dark train or the dim flashing crossing signal at the side of the road. In one previous study, a high risk subgroup of drivers involved in grade crossing accidents was found to be those of old age with associated degradation of visual acuity (3). The Goldsmith accident record also shows that the average age of the drivers involved in the fatal and injury accidents since 1966 was 67 and that all drivers involved in the three fatal accidents with seven deaths in 1971 were all over 70 years of age. The most likely primary cause of these high-accident record years was train and/or signal conspicuity inadequate to compensate for the advanced age of the drivers and the conditions described.

The Data Collection System

1. The 16 mm camera system used at the Goldsmith crossing was effective, inexpensive and quick to implement and also provided an excellent record of the conditions during data collection.

FHWA Data Base

1. The data obtained from FHWA, although adequate for its primary purpose of vehicle delay modeling, proved to be of little value in this study.

Overall Comparison

1. Although an exact value of added effectiveness of the after system (gates plus larger flashers plus strobe lights plus Marquardt predictor) could not be determined when compared to the before system, the approach speed profiles of drivers approaching this crossing indicate that they are being alerted earlier and more effectively with the after system. This type of installation should be strongly considered for other high hazard crossing locations when upgrading of present protection is planned.

Closure

The Southern Pacific Transportation Company is widely known for their use of automatic gates at railroad grade crossings. For several years they have averaged installing 200 per year or 39% of the average of 519 total installed for the United States. Their philosophy is that "where" and "under what conditions" they should be used cannot be modeled mathematically. They know they are effective and believe they are worth the cost and install them wherever (including some branch lines as well as main line tracks) they feel that they are proper.[1] There have been long range studies (1942-1966) on their installations which prove that they are effective and that they save lives.

The Transportation Research Board (TRB) Committee on Highway-Railroad Grade Crossings has recently compiled a list of research priorities in regard to grade crossings. Number one on the list is "Driver Reaction to Active Warning Systems." This includes suggested areas such as 1) the visibility and attention attracting properties of warning devices, 2) minimum conspicuity levels of signals and trains,

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[1] Private communication, H. M. Williamson, Chief Engineer

3) driver reaction to innovative signals such as highway traffic signals and variable message signs, 4) variation in warning time that drivers will accept, 5) gate arm conspicuity and activation times and 6) study of system cost. In short, several problems that this study has addressed are still research items of high priority and will continue to be until several controlled field studies have been completed.

There is a need for continued research to seek and find answers, to quantify, to model, to find measures of effectiveness, to understand driver behavior, etc. This is the role of research and must continue. On the other hand, there is a need to continue improving grade crossing safety, to save lives, to use whatever methods or systems are known to accomplish this end regardless of any unanswered questions regarding "why." This is the role of engineering and it too must continue.

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APPENDICES

APPENDIX A

SELECTED SPEED DISTRIBUTION DATA AND CURVES OF FREE-FLOW VEHICLES

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SELECTED SPEED DISTRIBUTION DATA AND CURVES OF FREE-FLOW VEHICLES

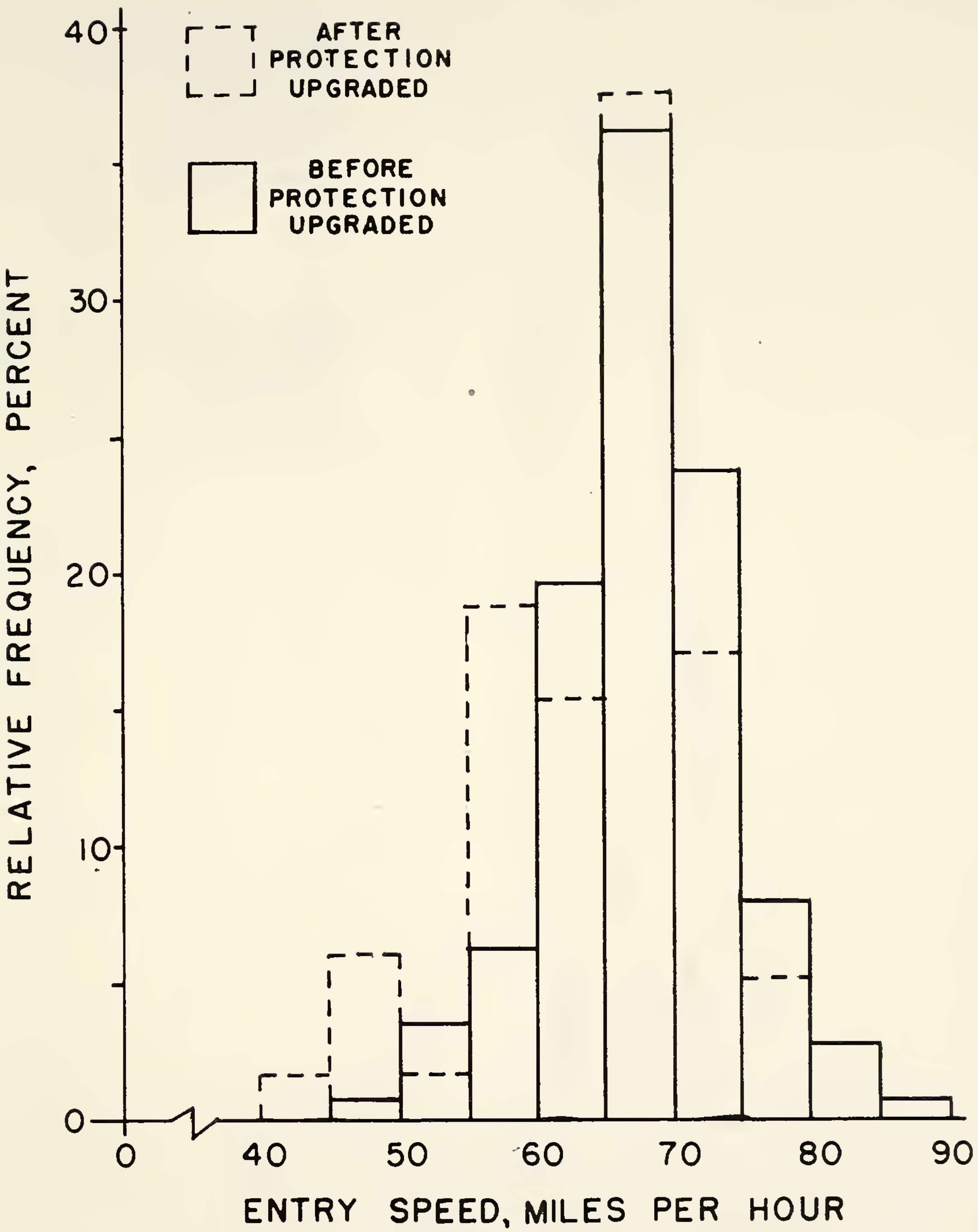

FIGURE A1 SPEED DISTRIBUTION, HISTOGRAM OF BEFORE AND AFTER DATA FOR FREE-FLOW SOUTHBOUND CARS ENTERING SYSTEM AT TRAP NO. 1.

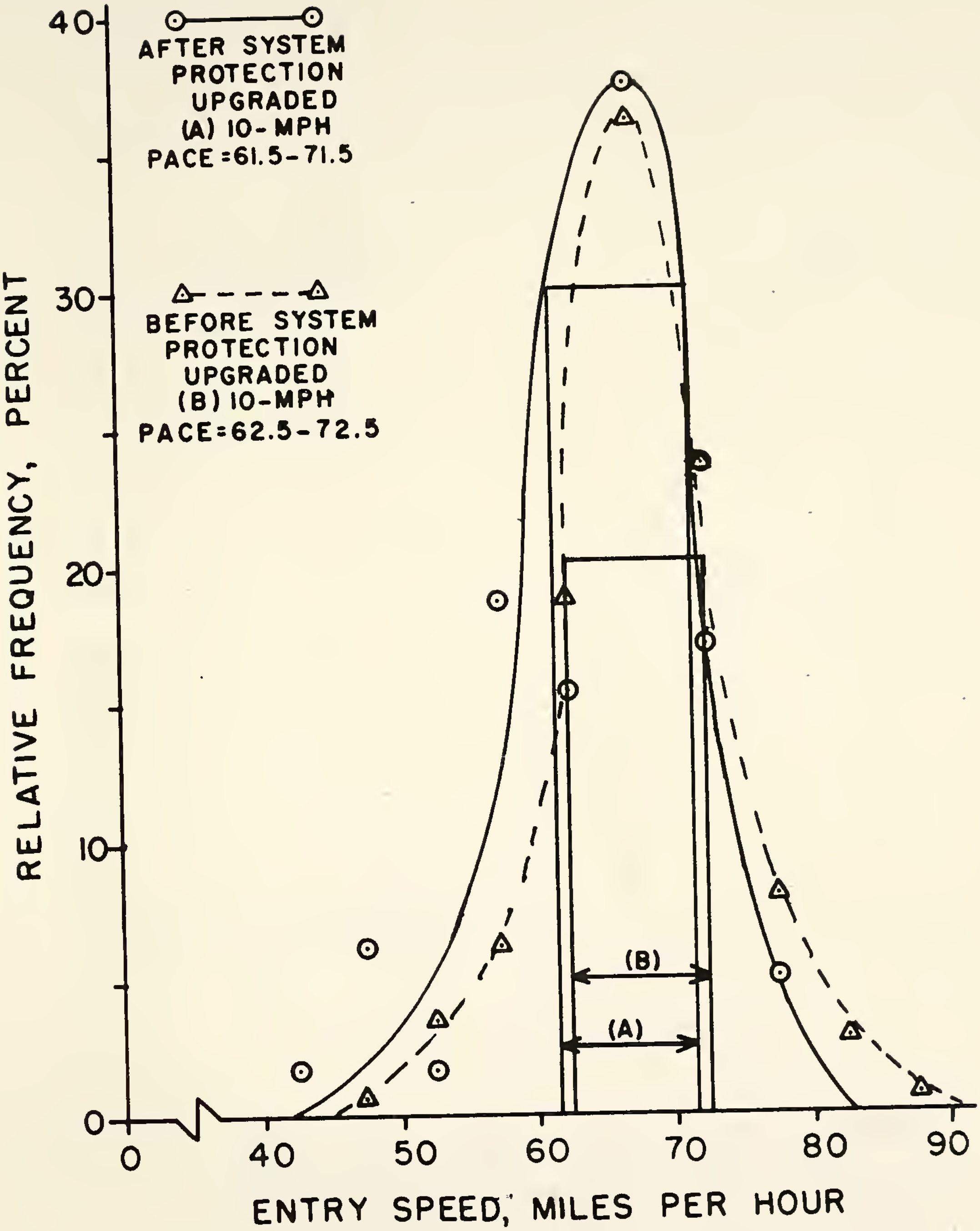

FIGURE A2 FREQUENCY DISTRIBUTION CURVE OF BEFORE AND AFTER DATA FOR FREE-FLOW, SOUTHBOUND CARS ENTERING SYSTEM AT TRAP NO. 1.

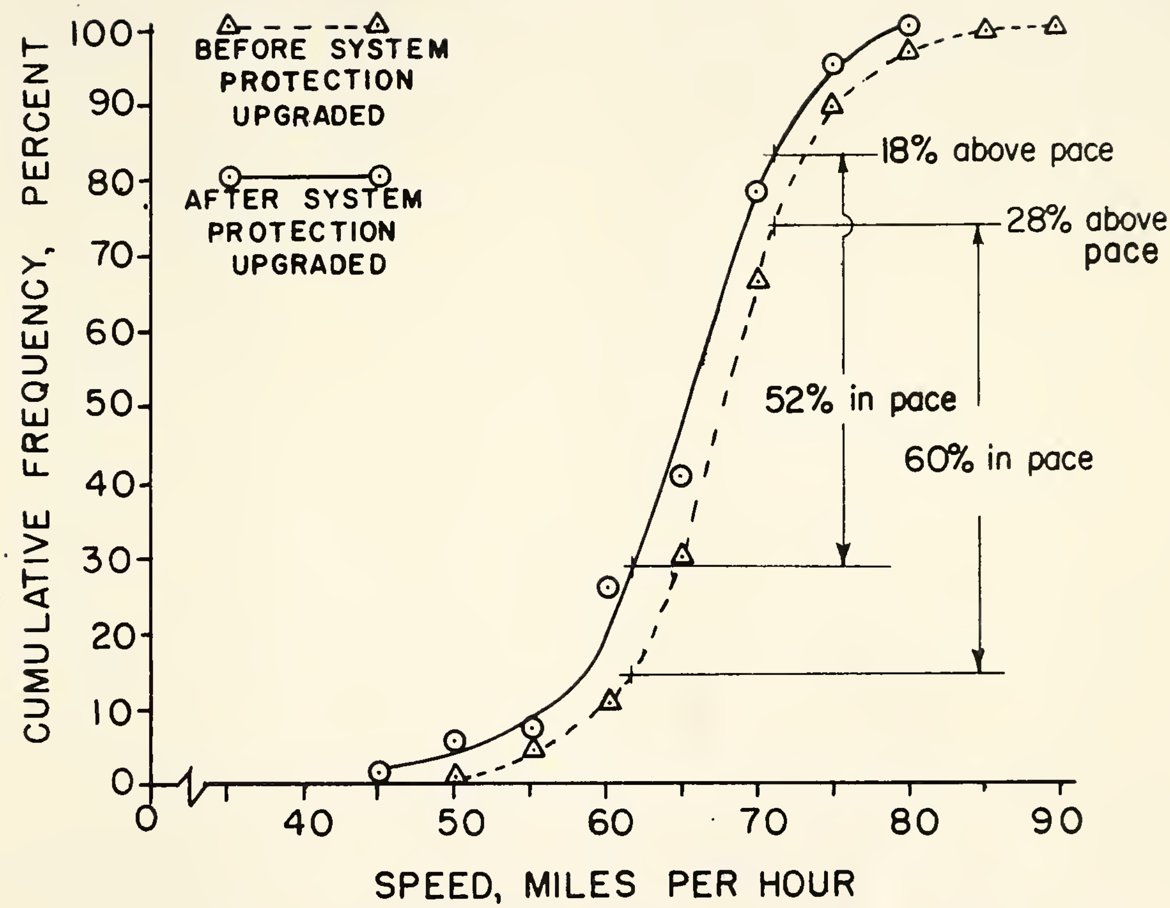

FIGURE A3 CUMULATIVE SPEED CURVE OF BEFORE AND AFTER DATA FOR FREE-FLOW, SOUTHBOUND CARS ENTERING SYSTEM AT TRAP NO. 1.

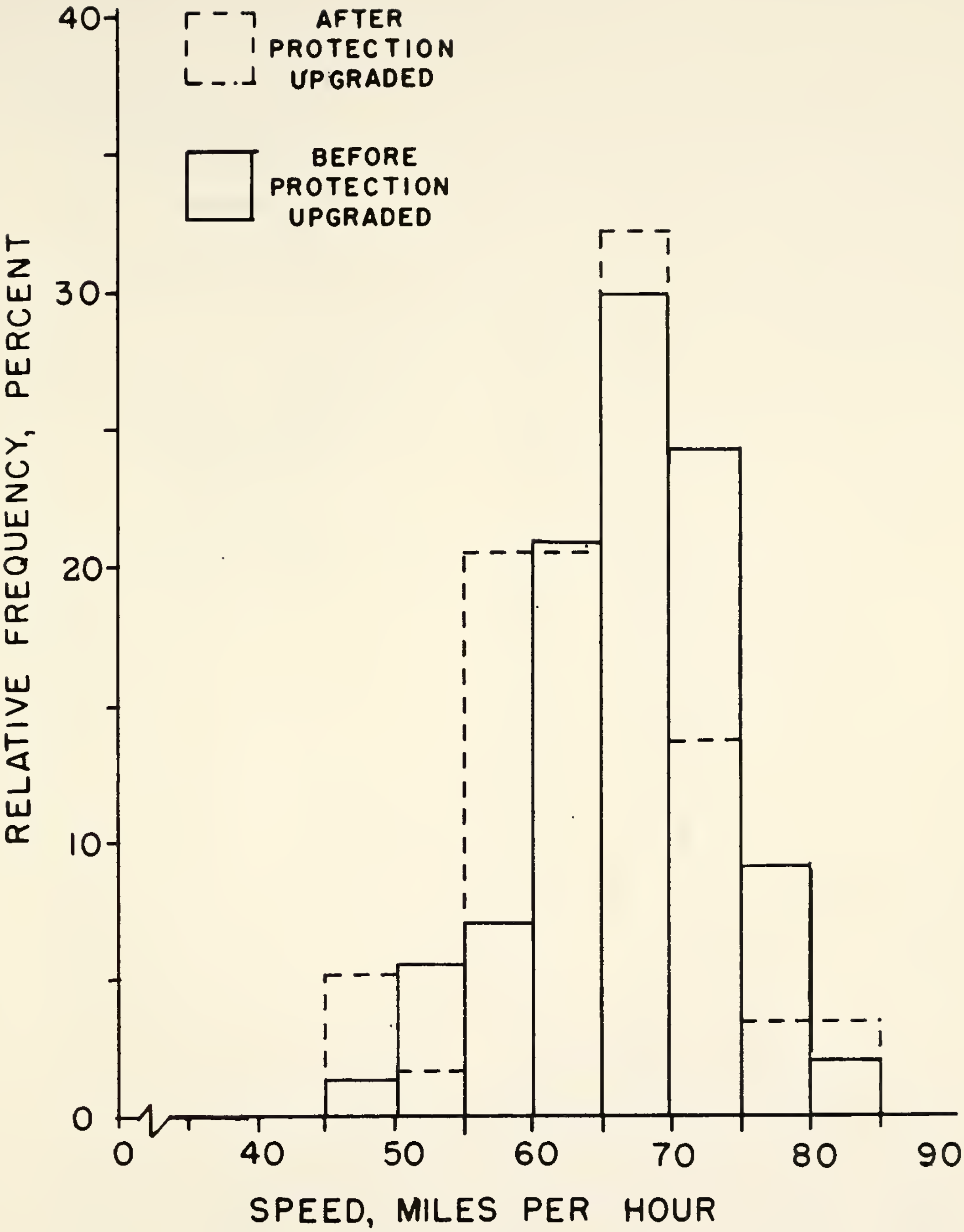

FIGURE A4 SPEED DISTRIBUTION HISTOGRAM OF BEFORE AND AFTER DATA FOR FREE-FLOW, SOUTHBOUND CARS AT TRAP NO. 5.

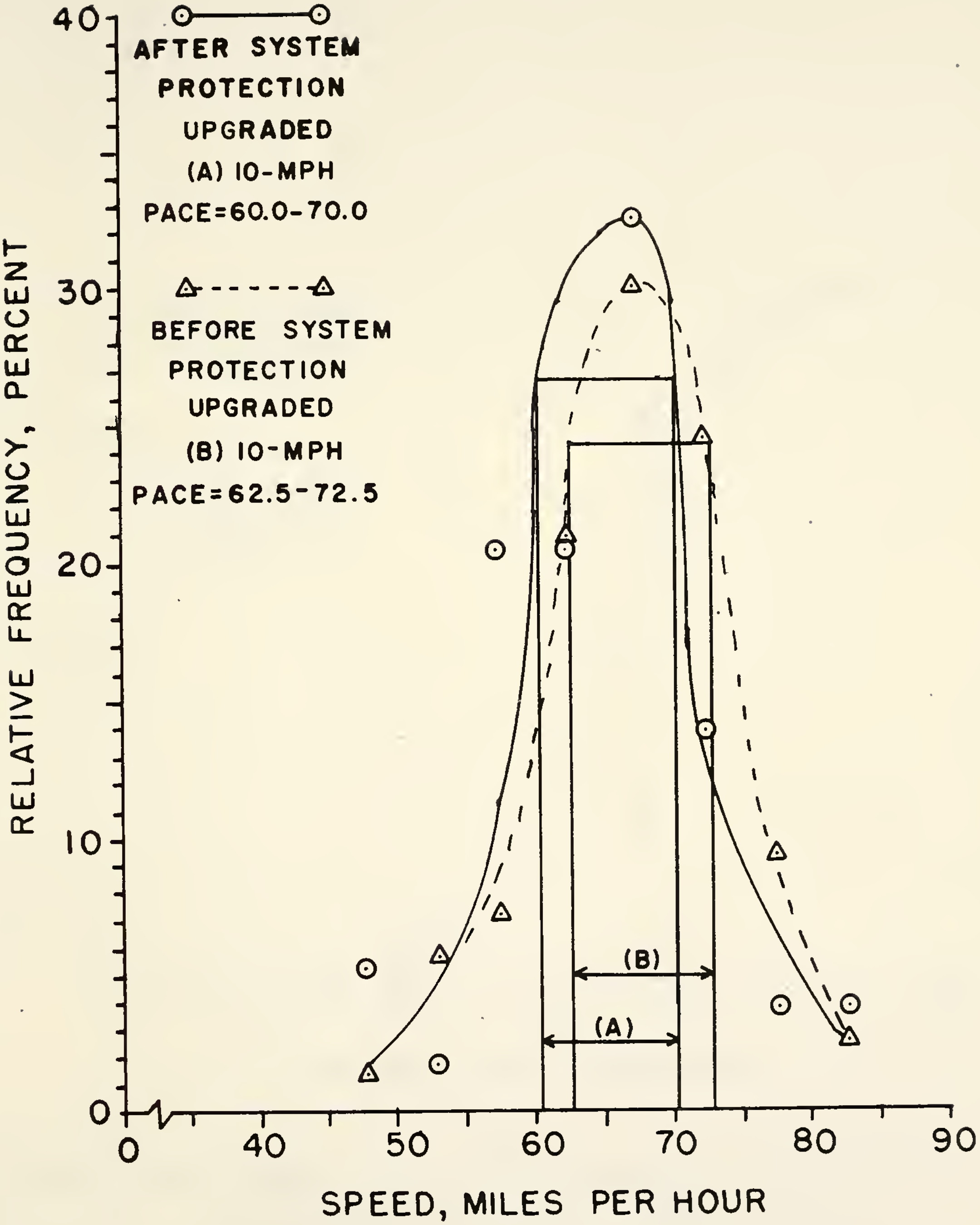

FIGURE A5 FREQUENCY DISTRIBUTION CURVE OF BEFORE AND AFTER DATA FOR FREE-FLOW, SOUTHBOUND CARS AT TRAP NO. 5.

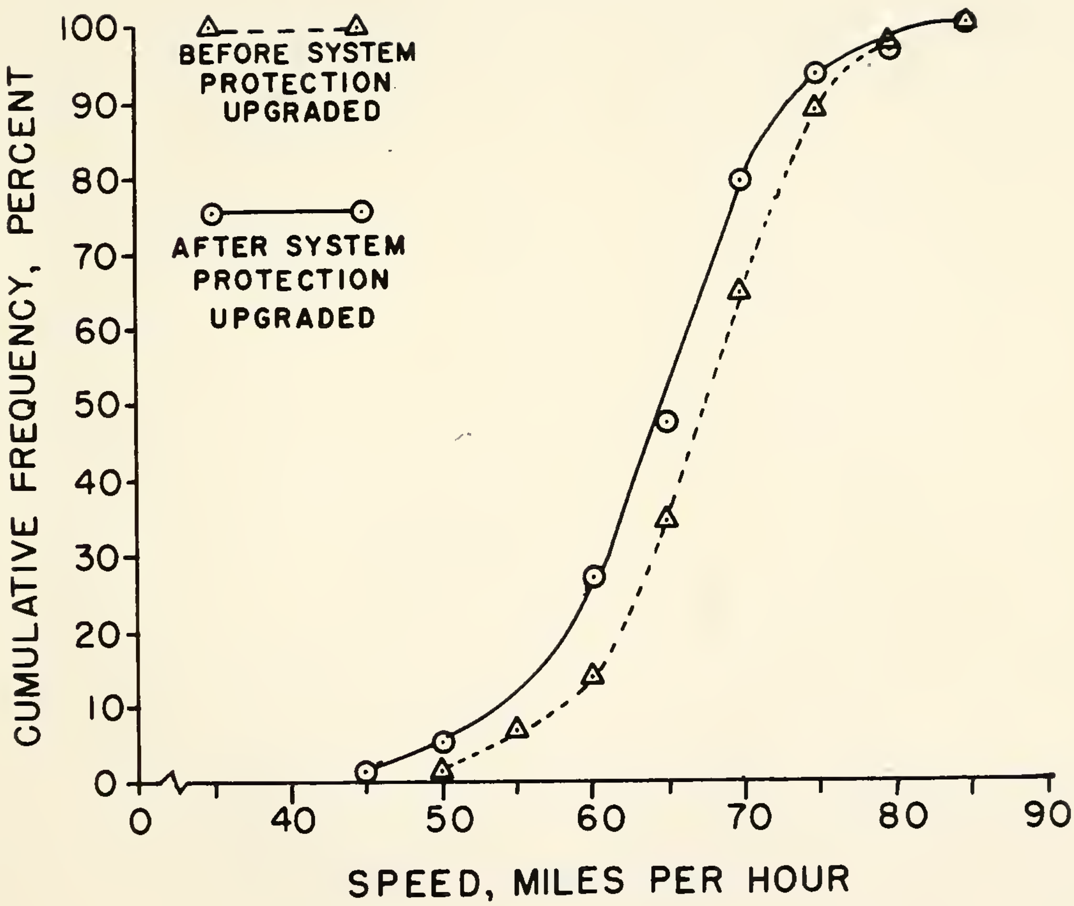

FIGURE A6 CUMULATIVE SPEED CURVE OF BEFORE AND AFTER DATA FOR FREE-FLOW, NORTHBOUND CARS AT TRAP NO. 5.

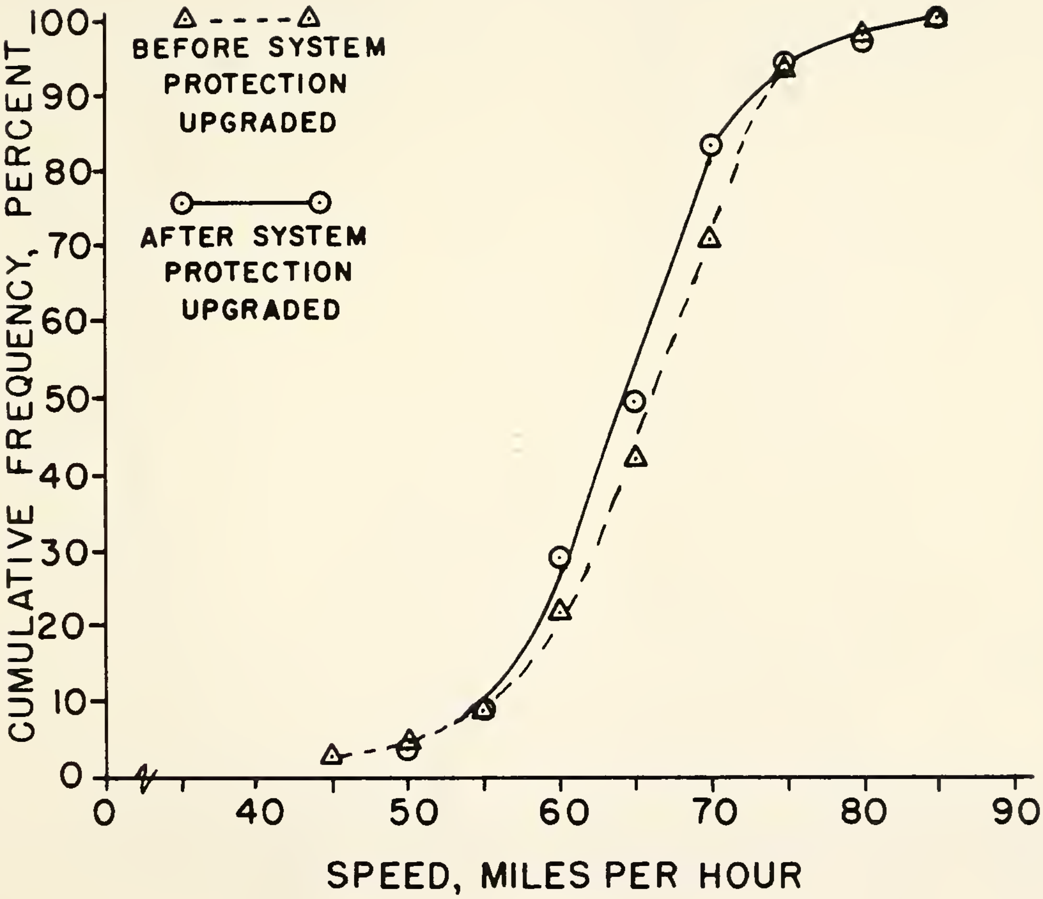

FIGURE A7 CUMULATIVE SPEED CURVE OF BEFORE AND AFTER DATA FOR FREE-FLOW, SOUTHBOUND CARS AT TRAP NO. 8.

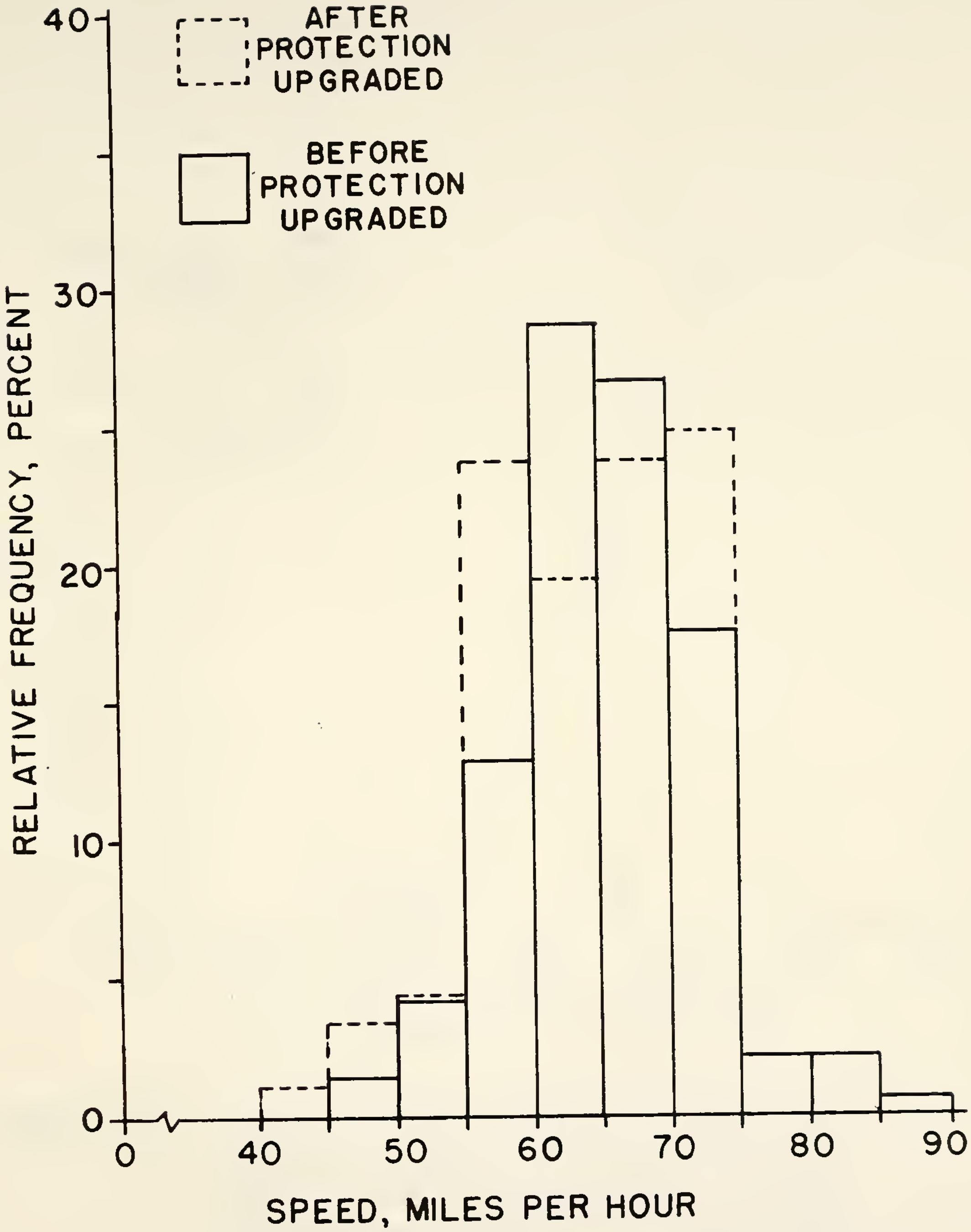

FIGURE A8 SPEED DISTRIBUTION, HISTOGRAM OF BEFORE AND AFTER DATA FOR FREE-FLOW NORTHBOUND CARS ENTERING SYSTEM AT TRAP NO. 1.

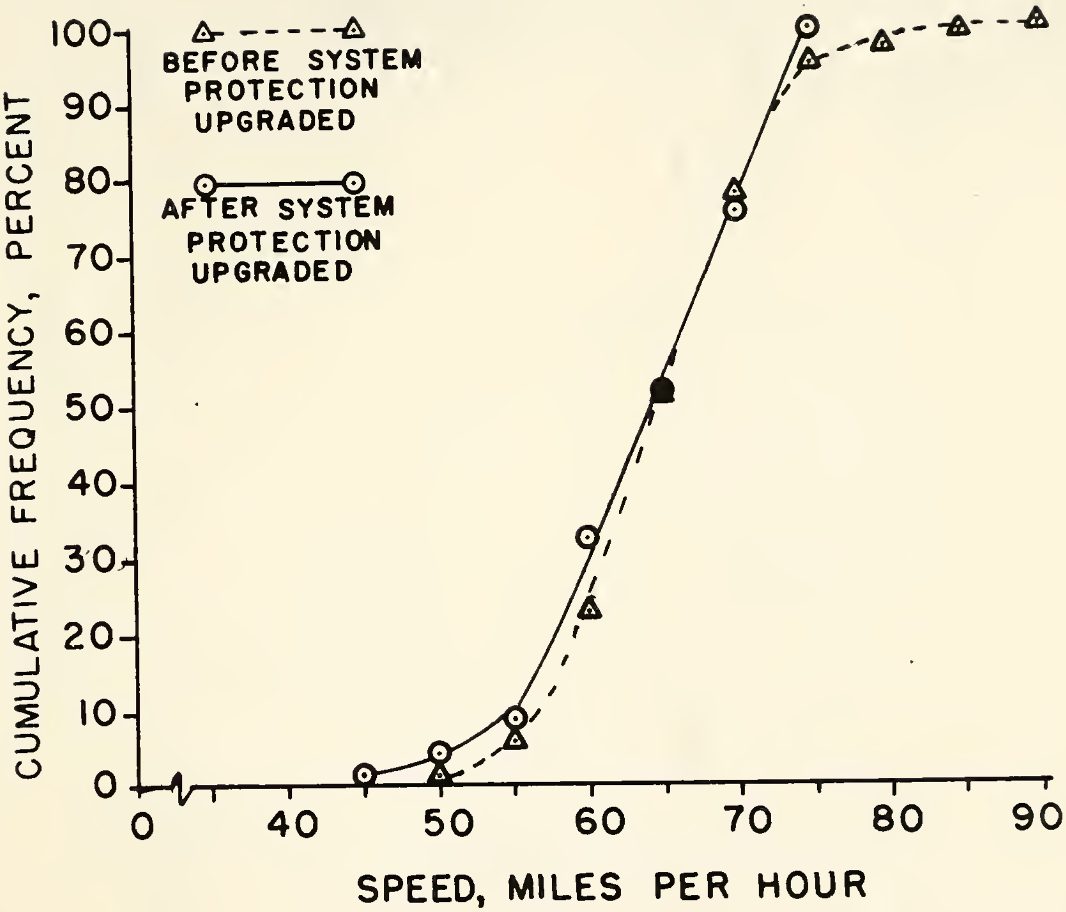

FIGURE A9 CUMULATIVE SPEED CURVE OF BEFORE AND AFTER DATA FOR FREE-FLOW, NORTHBOUND CARS ENTERING SYSTEM AT TRAP NO. 1.

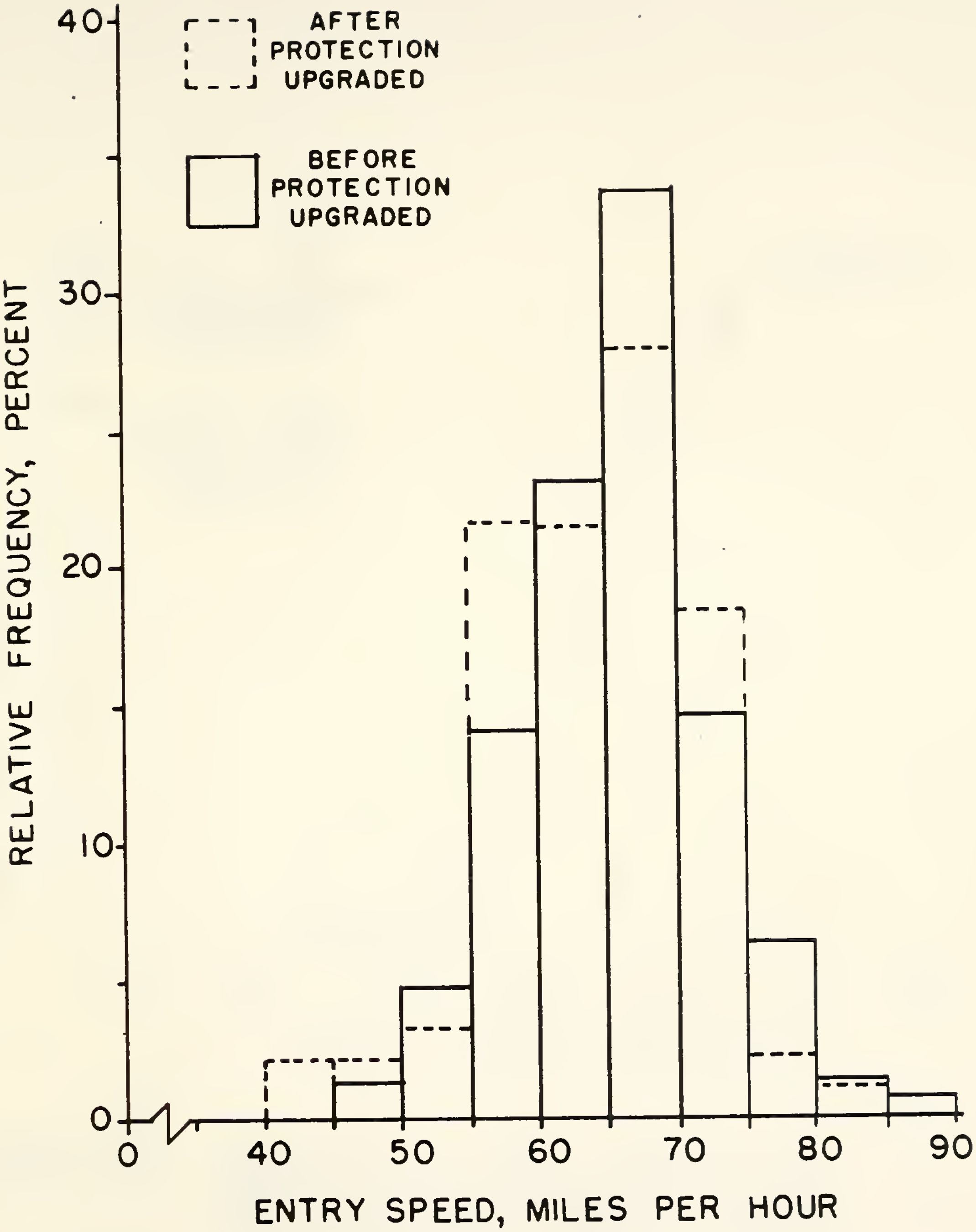

FIGURE A10 SPEED DISTRIBUTION HISTOGRAM OF BEFORE AND AFTER DATA FOR FREE-FLOW NORTHBOUND CARS AT TRAP NO. 5.

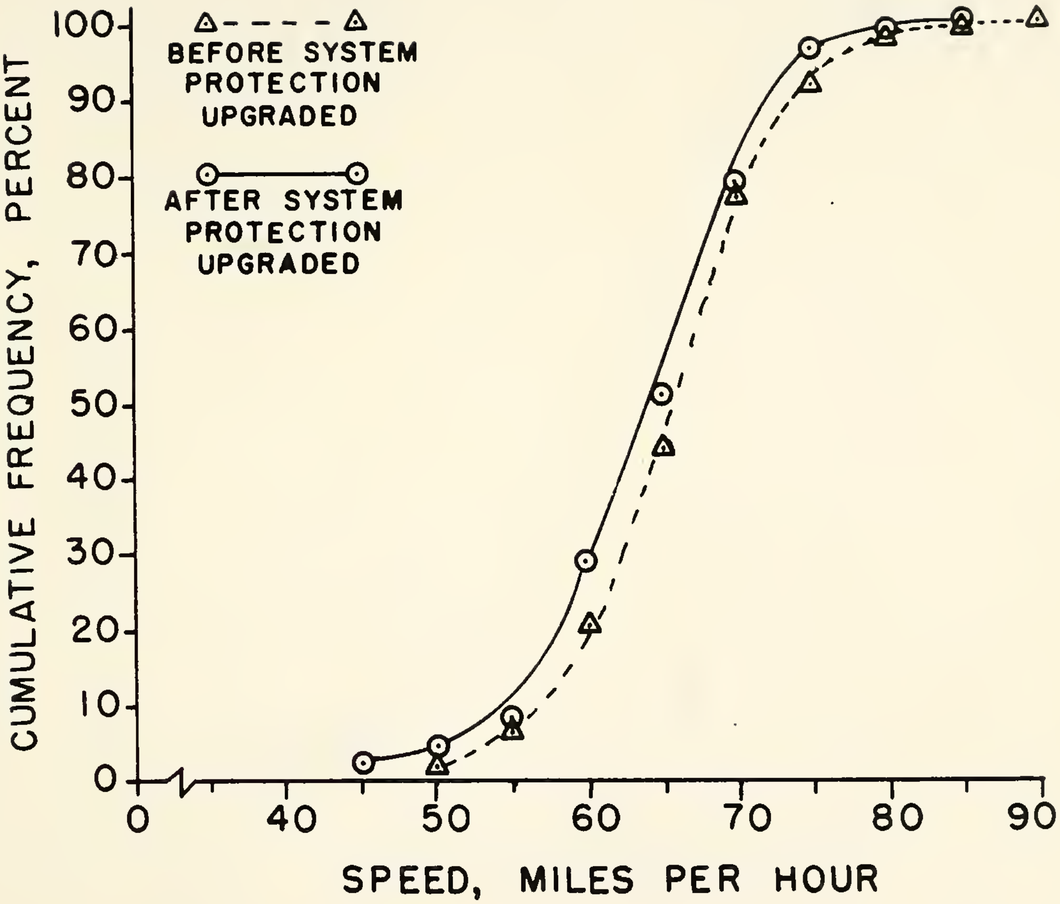

FIGURE A11 CUMULATIVE SPEED CURVE OF BEFORE AND AFTER DATA FOR FREE-FLOW, NORTHBOUND CARS AT TRAP NO. 5.

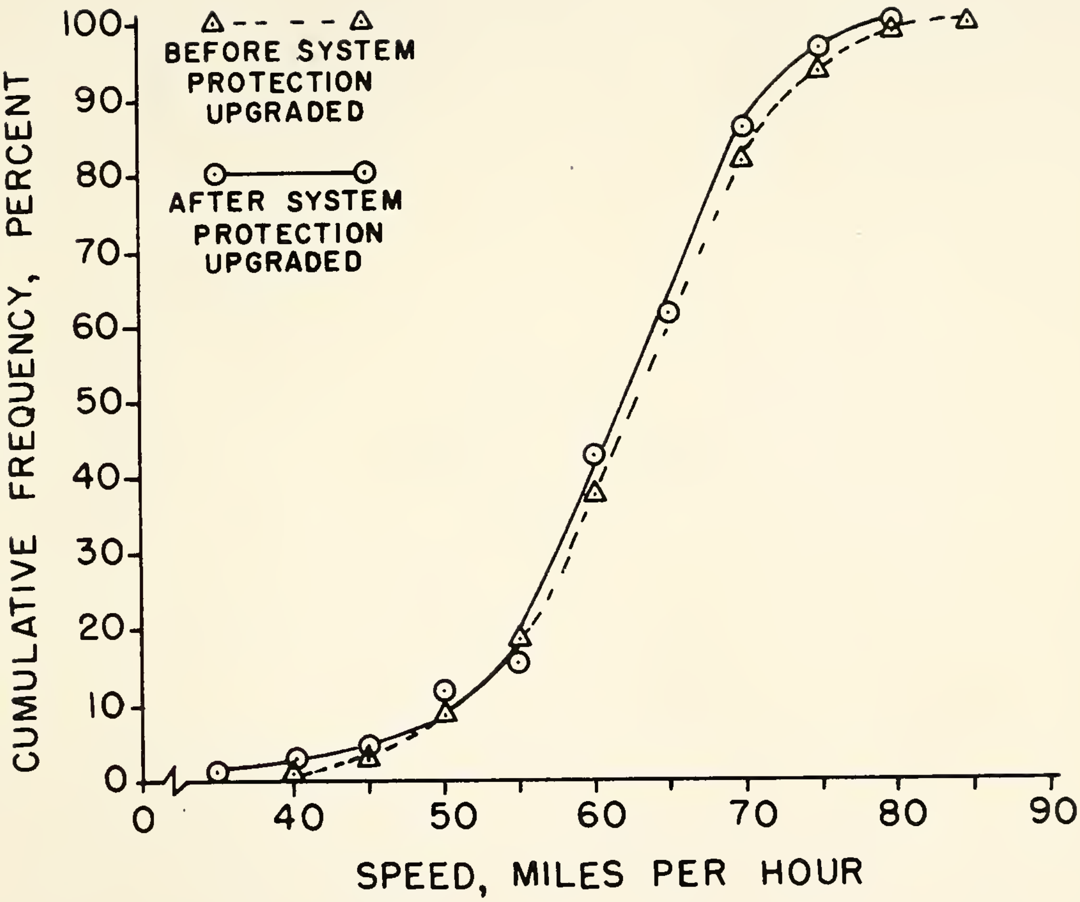

FIGURE A12 CUMULATIVE SPEED CURVE OF BEFORE AND AFTER DATA FOR FREE-FLOW, NORTHBOUND CARS AT TRAP NO. 8.

APPENDIX B

SUMMARY OF THE FHWA DATA SET

TABLE B1. ATTACHMENT A REFERRED TO IN EXPLANATION OF ANNOTATED LISTINGS

Tape=RAILBU

Index No.	Description	Disk File Parameters Start	No. of Vehicles	Disk File Parameters Space	Loc	Ind
1	Site 16-11 MD. Rt. 382 Croom Road 2/16/72 Lane 2 Croom Road	1	132	137	20675	79
2	Site 16-11 MD. Rt. 382 Croom Rd. 2/16/72 Lane 1 Croom Rd.	138	70	75	213	3
3	Site 16-29 Hillmeade Rd. 2/22/72 Lane 2 Hillmeade	213	66	71	284	4
4	Site 16-29 Hillmeade Rd. 2/22/72 Lane 1 Hillmeade	284	101	106	390	5
5	Site 16-29 Hillmeade Rd. 2/22/72 Lane 2 Hillmeade	390	18	23	413	6
6	Site VA-A-15 Rt. 15,Bussiness Wattenton, Va. 3/9/72 9.38-3.30 Lane 2 Rt. 15 Bus. Warrenton, Va	413	203	208	621	7
7	Site 16-29 Hillmeade Rd. 2/22/72 Lane 1 Hillmeade	621	12	17	638	8

TABLE B1. (continued)

8	Site 15-9 Randolph Rd. 2/28/72 1812-0023 Lane 2 Randolph Rd.	638	1660	1665	2303	9
9	Site 16-29 Hillmeade Rd. 2/22/72 Lane 2 Hillmeade	2303	66	71	2374	10
10	Site-RT55 The Plains Va. 3/14/72 0742-0815 Lane 2 VA-55	2374	35	40	2414	11
11	Site 16-1 Cedarville Rd. 3/29/72 Lane 2 Cedarville	2414	275	280	2694	12
12	Site 8-11 Sub-Station Rd. Deploy Plan 2/25/72 0920-1800 Lane 2 Sub-Station	2694	214	219	2913	13
14	Site 10-52 Rt. 194, New Midway MD 3/8/72 12.10-13.24 Location 1 Lane 1 Rt 194 New Midway MD	3073	27	32	3105	15
15	Site 16-29 Hillmeade Rd. 2/22/72 Lane 1 Hillmeade	3105	41	46	3151	16
16	Site 16-42 Sunnyside Ave 2/24/72 Aft. to Sunset Lane 2 Sunnyside	3151	170	175	3326	17

TABLE B1. (continued)

17	Site 16-42 Sunnyside Ave. 2/24/72 Sunset till Rain Lane 2 Sunnyside	3326	160	165	3491	18
18	Site 16-42 Sunnyside Ave 2/24/72 Sunset till Rain Lane 1 Sunnyside	3491	139	144	3635	19
19	Site 16-42 Sunnyside Ave Rain Lane 2 Sunnyside	3635	58	63	3698	20
20	Site-RT55 The Plains VA. 3/14/72 0742-0815 Lane 1 VA-55	3698	39	44	3742	21
21	VA-F-28 Calverton 3/18/72 0800-1400 Lane 2 VA-F-28	3742	137	142	3884	22
22	Site 16-14 MD FT. 301 2/17/72 Lane 3 & 4 MD RT 301	3884	98	103	3987	23
23	Site 16-14 MD RT. 301 2/17/72 Lane 1 & 2 MD RT 301	3987	147	152	4139	24
24	Site 15-13 Redland RD 3/2/72 3.45PM-6.3PM Lane Redland RD	4139	445	450	4589	25

TABLE B1. (continued)

25	Site VA-PW28 3/10/72 11.02 to 11.43 Lane 1 VA-PW28	4589	59	64	4653	26
26	Site - RT55 The Plains VA. 0815-0200 PM Lane 1 VA-55	4653	228	233	4886	27
27	Site 10-5 RT28, Point of Rocks, MD. Eval 1 3/7/72 8.00AM-3.00PM Lane 1 FT28 Point of Rocks MD	4886	87	92	4978	28
28	Site 10-48 MD 550, Woodsboro Eval 1 3/8/72 12.25-18.00 Lane 1 MD 550 Woodsboro	4978	88	93	5071	29
29	Site 16-50 Tanglewood 3/2/72 9.12-3.05 Lane 2 Tanglewood	5071	159	164	5235	30
30	Site 15-9 Randolph Rd 2/28/72 1352-1812 Lane 1 Randolph Rd	5235	1152	1157	6392	31
31	Site-RT55 The Plains VA. 3/14/72 0815-0200PM Lane 2 VA-55	6392	360	365	6757	32
32	Site 16-50 Tangle wood 3/2/72 9.12-3.05 Lane 1 Tanglewood	6757	262	267	7024	33

TABLE B1. (continued)

33	Site 16-42 Sunnyside Ave 2/24/72 Aft. to Sunset Lane 1 Sunnyside	7024	181	186	7210	34
34	Site 8-11 Sub-Station RD Deploy Plan 0920-1800 2/25/72 Lane 1 Substation	7210	247	252	7462	35
35	Site 16-1 Cedarville RD 2/29/72 Lane 1 Cedarville	7462	40	45	7507	36
36	Site 10-52 RT. 194, New Midway MD 3/8/72 12.10-13.24 Location 1 Lane 2 RT 194 New Midway RD	7507	68	73	7580	37
37	Site 10-52 RT 194, New Midway MD 3/8/72 14.36-18.30 Location 2 Lane 1 RT 194 New Midway RD	7580	240	245	7825	38
38	Site 10-52 RT 194, New Midway MD 3/8/72 14.36-18.30 Location 2 Lane 2 RT 194 New Midway MD	7825	144	149	7974	39
39	Site 10-5 RT28, Point of Rocks, MD Eval 1 3/7/72 8.00AM-3.00PM Lane 2 RT28 Point of Rocks MD	7974	128	133	8107	40

TABLE B1. (continued)

Tape=RAILBW

40	Site 10-48 MD 550, Woodsboro Eval 1 3/7/72 12.25-18.00 Lane 2 MD 550 Woodsboro	8107	142	147	8254	41
41	Site VA-15 3/12/72 12.51 to 18.57 Lane 2 VA-15	8254	350	355	8609	42
42	Site VA-15 2/12/72 12.51 to 18.57 Lane 1 VA-15	8609	218	223	8832	43
43	Site Berekeley Co. W. VA. 3/11/72 10.07 to 16.20 Lane 1 Berkeley Co	8832	72	77	8909	44
44	Site 15-13 Redland RD 2/2/72 3.45PM - 6.37PM Lane 1 Redland Rd	8909	0	5	8914	45
45	Site 15-13 Redland RD 3/2/72 6.37PM - 10.00PM Lane 1 Redland RD	8914	252	257	9171	46
46	Site VA-PW28 3/10/72 11.02 to 11.43 Lane 2 VA-PW28	9171	71	76	9247	47
47	Site VA-PW28 3/10/72 11.43-17.02 Lane 2 VA-PW28	9247	783	788	10035	48

TABLE B1. (continued)

48	Site VA-PW28 3/10/72 11.43-17.02 Lane 1 VA-PW28	10035	624	629	10664	49
49	Site VA-652 3/18/72 Day 1 0804-1355 Lane 2 VA-652	10644	151	156	10820	50
50	Site VA-652 3/18/72 Day 1 0804-1355 Lane 1 VA-652	10820	154	159	10979	51
51	Sete VA-652 3/19/72 Day 2 0907-1509 Lane 2 VA-652	10979	150	155	11134	52
52	Site VA-652 3/19/72 Day 2 0907-1509 Lane 1 VA-652	11134	147	152	11286	53
53	Site Jeff Duffields W.VA. 3/11/72 9.30 to 12.20 Lane 2 Jeff Duffields	11286	19	24	11310	54
54	Site Jeff Duffields W.VA. 3/11/72 9.30 to 12.20 Lane 1 Jeff Duffields	11310	37	42	11352	55
55	Site Jeff Duffields W.VA. 3/11/72 12.20 to 13.30 Lane 2 Jeff Duffields	11352	15	20	11372	56

TABLE B1. (continued)

56	Site Jeff Duffields W.VA. 3/11/72 12.20 to 13.30 Lane 1 Jeff Duffields	11372	20	25	11397	57
57	Site Jeff Duffields W.VA. 3/11/72 13.30 to 16.30 Lane 2 Jeff Duffields	11397	6	11	11408	58
58	Site Jeff Duffields W.VA. 3/11/72 13.30 to 16.30 Lane 1 Jeff Duffields	11408	54	59	11467	59
59	Site 2-42 Eval 2 3/6/72 12.01 - 17.30 Lane 2 2-42	11467	4	9	11476	60
60	Site 2-42 Eval 2 3/6/72 12.01 - 17.30 Lane 1 2-42	11476	245	250	11726	61
61	Site VA 234 3/12/72 15.55 to 20.00 Lane 3 & 4 VA-234	11726	1103	1108	12834	62
62	Site VA 234 3/12/72 15.55 to 20.00 Lane 1 & 2 VA-234	12834	39	44	12878	63
63	Site 15-X Little Falls Pkwy 3/6/72 7.32AM-1.31PM Lane 1 & 2 15-X	12878	346	351	13229	64

TABLE B1. (continued)

64	Van Dorn Ave West Side 9.00 - 3.00 Lane 1 & 2 Van Dorn Ave WS	13229	175	180	13409	65
65	Site 15-3 Bethesda Ave 3/19/72 0800-0945 Lane 1 Bethesda	13409	6	11	13420	66
66	Site 15-3 Bethesda Ave 3/19/72 0800-0945 Lane 2 Bethesda	13420	13	18	13438	67
67	Site 15-3 Bethesda Ave 3/19/72 094501430 Lane 2 Bethesda	13438	137	142	13580	68
68	Site 15-3 Bethesda Ave 3/19/72 0945-1430 Lane 1 Bethesda	13580	84	89	13669	69
69	Site 16-19 Central Ave South Eval 2 3/21/72 1015-1620 Lane 1 & 2 Central Ave South	13669	267	272	13941	70
70	Site 16-19 Central Ave North Eval 1 3/21/72 Lane 1 & 2 Central Ave North	13941	277	282	14223	71
71	VA-F-28 Calverton 3/18/72 0800-1400 Lane 1 VA-F-28	14223	246	251	14474	72

TABLE B1. (continued)

72	Van Dorn Ave East Side Eval 1 3/1/72 9.00 - 3.00 Lane 1 & 2 Van Dorn Ave East	14474	2490	2495	16969	73
73	Site 16-42 Sunnyside Ave 2/24/72 Rain Lane 1 Sunnyside	16969	71	76	17045	74
74	Site 15-X Little Falls Pkwy 3/6/72 7.32AM-1.31PM Lane 3 & 4 15-X	17045	718	723	17768	75
75	Site 15-9 Randolph Road 2/28/72 1352-1812 Lane 2 Randolph	17768	1266	1271	19039	76
76	Site 15-9 Randolph Road 2/28/72 1812-0023 Lane 1 Randolph	19039	1199	1204	20243	77
77	Site Berkeley Co. W.VA. 3/11/72 10.07 to 16.20 Lane 2 Berkeley Co	20243	64	69	20312	78
78	Site 15-13 Redland RD 3/2/72 6.37PM - 10.00PM Lane 2 Redland RD	20312	358	363	20675	79

TABLE B2. EXPLANATION OF ANNOTATED LISTINGS

1. Data for each vehicle is in sets of five records, i.e., data recorded at each trap. One record is two lines of print as shown on the sample. Each logical record is 224 characters. Block size is √3360. Density is 800.

2. The Index shows the site specific information and number of vehicles observed. Other data relevant to each site are attached. (Attachment A)

3. The printed format for each record is as follows:

LINE 1:	Refer to:
a. Vehicle type (1-10)	Attachment B
b. Index number (1-78)	#2 above
c. Lane (1-4)	#2 above
d. Train presence	0 = no 1 = yes
e. Signal activation	0 = no 1 = yes
f. Time of day Hr. xx Min. yy Sec. zz	
g. Front axle time (miliseconds) (multiply x 10^7)	
h. Rear axle time (milliseconds)	
i. Front axle speed (mph)	
j. Rear axle speed (mph)	
k. Average axle speed (mph) (whole number part)	
l. Number of characters per logical record	

LINE 2:

m. Average axle speed (mph) (decimal part)

n. Distance between axles (ft) - wheelbase

Passenger car - 12 feet

Two axle truck- 12-15 feet

Two and three axle bus - 15 feet plus vehicles coded as bus

TABLE B2. (continued)

*o. Time gap between leading vehicle and this vehicle(sec)

*p. Space gap between leading vehicle and this vehicle(ft)

*q. Space gap between this vehicle and following vehicle(ft)

*r. Time gap between this vehicle and following vehicle(sec)

* Overhangs of bumpers have been taken into account in measures of all gaps.

TABLE B3. ATTACHMENT "B" REFERRED TO IN EXPLANATION OF ANNOTATED LISTINGS

Type 1	Passenger car which did not stop
Type 2	2-axle truck which did not stop
Type 3	Bus which did not stop
Type 5	Truck combine which did not stop and not required to stop
Type 6	Passenger car which stopped
Type 7	2-axle truck which stopped
Type 8	Bus which stopped
Type 9	Truck combine which stopped and required to stop
Type 10	Truck combine which stopped and not required to stop

TABLE B4. PART OF SITE SPECIFIC INFORMATION PROVIDED (Source: Ref. 20, p. A-8)

Site:	8-11
Location:	Substation Road, Charles Co., Md.
Type:	Rural
Published ADT:	360
Volume Designation:	Low
Data Collected:	25 March 1972
Hours:	0920-1820
Approximate Volume in Sample:	None
Railroad Company:	Penn Central Transportation Company

	Protection at Crossing	100' Sight Distance Left	100' Sight Distance Right	300' Sight Distance Left	300' Sight Distance Right	Roughness 5 = Rough
Lane 1	Crossbucks	100	50	50	25	4
Lane 2	Crossbucks	100	50	300	0	4

TABLE B4. (continued)

Speed Profile

Lane 1	n	Distance from Track (feet)				
		-864	-111	14	100	359
		Speed (mph)				
Passenger Cars	223	35.65	26.60	18.33	21.55	20.68
Two-axle Trucks	3	31.50	25.30	18.00	19.50	19.70

Lane 2	n	Distance from Track (feet)				
		363	-104	12	107	860
		Speed (mph)				
Passenger Cars	201	22.11	23.09	18.03	23.25	32.47
Two-axle Trucks	4	19.50	19.90	16.50	20.90	30.40

TABLE B5. REFERENCE SITE AND INDEX NUMBERS AS LOCATED BY LINE COUNTS FROM PRINTING OUT THE FHWA TAPES*

Ref	Site	Index	Lane	Time	Comments	Tape	Line Count Begin	Line Count End	Vehicles
1	2-42	59	2	1201:1308	Eval. 2	2	16126	16140	3
		60	1	1201:1730	Eval. 2	2	16141	17365.	245
2	8-11	12	2	9020:1800	Deploy Plan	1	13026	14095	214
		34	1	0920:1800	Deploy Plan	2	35056	36290	247
3	10-5	27	1	0800:1500	Eval. 1	1	23611	24045	87
		39	2	0800:1500	Eval. 1	1	38751	39390	128
4	10-48	28	1	1225:1800	Eval. 1	1	24046	24485	88
		40	2	1225:1800	Eval. 1	2	1	710	142
5	10-52	14	1	1210:1324	Location 1	1	14871	15005	27
		36	2	1210:1324	Location 1	1	36491	36830	68
		37	1	1436:1800	Location 2	1	36831	38030	240
		38	2	1436:1730	Location 2	1	38031	38750	144
6	15-3	65	1	0800:0945		2	25621	25650	6
		66	2	0800:0945		2	25651	25715	13
		67	2	0945:1430		2	25716	26400	137
		68	1	0945:1430		2	26401	26820	84
7	15-9	8	2		Can't Locate				
		30	1	1352:1812		1	25281	31040	1152
		75	2	1352:1812		2	47166	53495	1266
		76	1	1812:0023		2	53496	59490	1199
8	15-13	24	2	1545:1837		2	19951	22175	445
		44	1	1010:1011		2	3911	3915	1
		45	1	1837:2200		2	3916	5175	252
		78	2	1837:2200		2	59811	61600	358
9	15-X	63	1&2	1330:1915		2	23016	24745	346
		74	3&4	1330:1915		2	43576	47165	718

TABLE B5. (continued)

10	16-1		2		Can't Locate				
		35	1	0906:1050		1	36291	36490	40
11	16-11		2		Can't Locate				
			1		Can't Locate				
12	16-14	22	3&4	0830-1200		1	18726	19215	98
		23	1&2	0830-1200		1	19216	19950	147
13	16-19	69	1&2	1015-1620	South	2	26821	28155	267
		70	1&2	1015-1620	North	2	28156	29540	
14	16-29		2		Can't Locate				
			1		Can't Locate				
			2		Can't Locate				
			1		Can't Locate				
			2		Can't Locate				
		15	1	1047:1259		1	15006	15210	41
15	16-42	16	2	1625:1750	Aft to Sunset	1	15211	16060	170
		17	2	1740:1942	Sunset to Rain	1	16061	16860	160
		18	1	1740:1940	Sunset to Rain	1	16861	17555	139
		19	2	1943:2133	Rain	1	17556	17845	58
		33	1	1625:1750	Aft to Sunset	1	34151	35055	181
		73	1	1943:2134	Rain	2	43221	43575	71
16	16-50	29	2	0900:1500		1	24486	25280	159
		32	1	0900:1505		1	32841	32150	262
17	30-28-								
	1	21	2	0800:1400		1	18041	18725	137
		71	1	0800:1400		2	29541	30770	246
18	30-55-								
	1	10	2		Can't Locate				
		20	1	0742:0815		1	17846	18040	39
		26	1	0815:1400		1	22471	23610	228
		31	2	0815:1400		1	31041	32840	360

TABLE B5. (continued)

19	76-15-1	41	2	2151:1857		1	711	2460	350
		42	1	1251:1857		1	2461	3550	218
20	76-28-1	25	1	1102:1143		1	22176	22470	59
		46	2	1102:1143		2	5176	5530	71
		47	2	1143:1702		2	5531	9325	759
		48	1	1143:1702		2	2936	12445	624
21	76-652-1	49	2	0804:1355		2	12446	13200	151
		50	1	0804:1400		2	13201	13970	154
		51	2	0907:1509	Day 2	2	13971	14720	150
		52	1	0907:1509	Day 2	2	14721	15455	147
22	100-VD-1	64	1&2	0900:1500	West Side	2	24746	25620	175
		27	1&2	0900:1500	East Side	2	30771	43220	2490
23	155-234-2	61	3&4	1555:2000		2	17366	22820	1091
		62	1&2	1555:2000		2	22821	23015	39
24	156-A15-1	6	1		Can't Locate				
		13	1	0938:1530		1	14096	14870	155
25	Jeff-erson	53	2	0930:1220		2	15456	15550	19
		54	1	0930:1220		2	15551	15735	37
		55	2	1220:1330		2	15736	15810	15
		56	1	1220:1330		2	15811	15910	20
		57	2	1330:1400		2	15911	15940	6
		58	1	1330:1630		2	15941	16125	37
26	Berk-eley	43	1	1113:1620		2	3551	3910	72
		77	2	1010:1620		2	59491	59810	64

*Table is organized in order of reference numbers and not in order on tapes

VITA

VITA

Eugene Robert Russell was born August 24, 1932, in Cromwell, Connecticut. He received his primary education in Cromwell and secondary education in Middletown, Connecticut, where he was graduated from Middletown High School in 1950.

He attended Hartford Institute of Technology for one year prior to being called to active duty with the U. S. Naval Reserve in 1951. After being discharged he resumed his education at Missouri School of Mines and Metallurgy (now University of Missouri - Rolla) where he received the Bachelor of Science Degree in Civil Engineering in 1958.

He worked until August 1962 in the Bridge Department of the California Division of Highways at which time he took a position with the Iowa Highway Commission as a Resident Construction Engineer.

In September 1963 he entered Iowa State University and received the Master of Science degree in August 1965. He joined the faculty of Indiana Institute of Technology, Fort Wayne, as an Assistant Professor in September 1965 and taught courses in all areas of Civil Engineering. In June 1969 he came to Purdue University as a Graduate Instructor to work toward the Ph.D. degree.

He is a Member of the American Society of Civil Engineers, a Member of the American Association of Engineering Education, an Associate Member of the Institute of Traffic Engineers, An Associate Member of Sigma Xi, and an affiliate of the National Association of County Engineers.

He is married and has 10 children.

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